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Partnerships Under Pressure

Managing Commercial Low-Level Radioactive Waste

J952-66

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

Almost 5 years have passed since the Low-Level Radioactive Waste Policy Amendments Act was enacted. The law establishes milestones and deadlines for States to develop disposal facilities for their low-level radioactive waste (LLW). Partnerships between States, called compacts, are encouraged to develop these facilities because of the small national volume of LLW. While most States and compacts are on track for developing facilities for most of their LLW, few States are far along in developing disposal capacity for mixtures of low-level and hazardous waste—so-called "mixed LLW."

OTA's study on managing LLW, including mixed LLW, was undertaken at the request of the Senate Committee on Environment and Public Works. The Committee asked OTA to analyze States' progress in developing disposal facilities for LLW and mixed LLW and to evaluate any existing problems in managing mixed LLW.

This report provides an overview of progress made by nine compacts and the remaining unaffiliated States in developing disposal facilities. Disposal costs have more than tripled while LLW volumes have dropped by more than half over the last decade. Since many costs associated with developing and operating a disposal facility are fixed, unit disposal costs will increase substantially as new facilities open. This may lead States to consider the economics of cooperative arrangements, which would permit them to trade waste services and construct fewer full-service disposal facilities.

A small percent of LLW is labeled mixed LLW because it also contains components classified as hazardous under the Resource Conservation and Recovery Act. Jurisdiction over mixed LLW disposal falls jointly to the Nuclear Regulatory Commission and the Environmental Protection Agency. Unfortunately, some regulations aimed at mixed LLW are unattainable, inconsistent, or duplicative. Unless current regulations are revised, generators of mixed LLW (e.g., industries, hospitals, nuclear power plants, and laboratories) are left with three options: stop producing the waste (which can mean going out of business), illegally store the waste, or illegally dispose of the waste. Our report presents options on how this dilemma may be addressed.

Substantial assistance was received from many organizations and individuals during the course of this study. We would like to express our thanks to our advisory panel, contractors, workshop participants, and reviewers who provided advice and information throughout the course of this study. As with all OTA studies, OTA remains solely responsible for the contents of this report.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the review panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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Chapter 1

Overview, Findings, and Policy Options

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Chapter 1

Overview, Findings, and Policy Options

OVERVIEW

What happens to commercial low-level radioactive waste (LLW)? Where do nuclear power plant workers discard their contaminated work uniforms, rags they used to clean instruments, and their old equipment? What happens to used organic solvents that are handled in radiopharmaceutical manufacturing? Where do hospital workers send obsolete instrumentation used to diagnose and treat cancer patients?

Since 1978, these and all other commercial LLW generated in the United States have been buried in three States—Washington, South Carolina, and Nevada. None of the other 47 States has an active disposal site. This situation prompted Congress to pass the Low-Level Radioactive Waste Policy Act of 1980[1], which requires every State to become responsible for disposing of the commercial LLW generated within its borders. Due to high disposal costs and small volumes of commercial LLW, States are encouraged to develop multi-State agreements in which one State hosts a disposal facility for all partners to the agreement. A partnership among States is called a compact. By December 31, 1985, these new facilities were to be operational, but the deadline was not met. The three States with sites threatened to shut the doors of their facilities to all States that were not members of their compacts. This prompted Congress to pass the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) during the final days of 1985.[2]

The LLRWPAA establishes a new deadline—December 31, 1992—after which operating facilities will be closed to out-of-region waste. By this date, States will have to develop new disposal sites or otherwise be able to manage their own waste. To enforce this deadline the LLRWPAA set interim milestones, penalties for unmet milestones, and volume restrictions and surcharges on LLW shipped to the three operating disposal facilities. These mandates will remain in effect until the December 31, 1992 deadline.

Compliance With the Low-Level Radioactive Waste Policy Amendments Act of 1985

It is not clear whether every State will be able to comply with the LLRWPAA. About a dozen LLW disposal facilities are now slated for development (see figure 1-1), but it is questionable whether every State will belong to a compact or will be able to manage its own waste when it loses access to the three operating sites on January 1, 1993. A reduced number of facilities could easily handle the Nation's LLW.

States and compacts may try cooperative agreements to manage their LLW. Such an agreement could involve one State or compact paying another State or compact to take its waste or involve States and compacts trading waste types or waste services. It is hard to predict how successful such cooperative agreements will be.

Shrinking Volume Means Rising Disposal Costs

One factor that has made the development of multiple disposal sites difficult is the increase in unit disposal costs resulting from shrinking LLW volumes. Nationwide, LLW volumes have declined by about half in the last 9 years and could decline by another half again by 1993. The incentive for these reductions has been and will largely be surcharges added to disposal costs.

Volume is a major determinant of unit disposal cost. Smaller volumes mean higher costs per unit because many of the costs of developing and maintaining LLW disposal sites are fixed. With the Nation shifting from having three disposal sites to having a dozen or more, unit disposal costs will probably rise dramatically.

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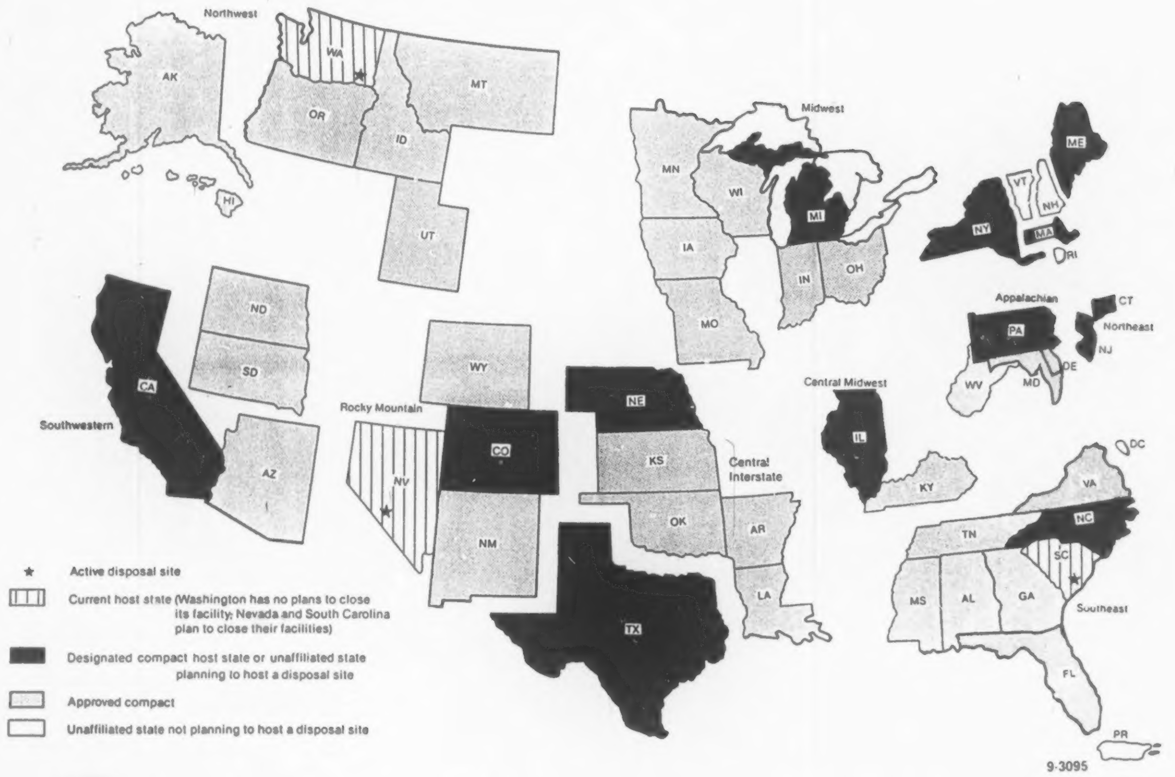
[1] Public Law 96-573, Dec. 22, 1980.

[2] Public Law 99-240, Jan. 15, 1986.

Figure 1-1—Status of Compact Regions and Unaffiliated States


Northwest
AK
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OH
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ME
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NH
NY
MA
RI
Appalachian
PA
CT
Northeast
NJ
DE
MD
WV
Central Midwest
IL
KY
DC
VA
NC
TN
SC
MS
AL
GA
Southeast
FL
PR
Southwestern
CA
ND
SD
AZ
Rocky Mountain
NV
WY
CO
NM
NE
KS
OK
TX
Central Interstate
AR
LA
★ Active disposal site
Current host state (Washington has no plans to close its facility; Nevada and South Carolina plan to close their facilities)
Designated compact host state or unaffiliated state planning to host a disposal site
Approved compact
Unaffiliated state not planning to host a disposal site
9-3095

SOURCE: Updated from the U.S. Department of Energy, *1987 Annual Report on Low-Level Radioactive Waste Management Progress*, DOE-NE-00984 (Washington, DC: August 1988).

Management Problems for Mixed Low-Level Radioactive Waste

An issue of immediate concern in managing LLW is the regulation of *mixed* LLW—waste that is both radioactive, as defined in the LLRWPAA, and hazardous, as defined by the Resource Conservation and Recovery Act (RCRA).[3] This waste is regulated by both the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). Some specific regulations cannot be met, some regulations may be in conflict and inconsistent, and other regulations overlap and are duplicative.

Although mixed LLW comprises less than 10 percent of all LLW, it has been identified by States as their major concern in managing LLW. No disposal facility for mixed LLW has been available since 1985. Also, no offsite storage or treatment facility is available. Since mixed LLW is a subset of LLW, States will have to be able to manage their mixed LLW if they are to meet the milestones of the LLRWPAA. Most LLW generators are using all available management techniques to alter their practices in order to generate either exclusively radioactive waste or exclusively hazardous waste. By doing so, disposal of the waste is possible. Yet, the generation of some mixed LLWs is unavoidable.

Ad hoc surveys indicate that the cumulative onsite storage of mixed LLW is holding steady for the majority of generators, even though none is allowed to be disposed and new mixed LLW is being generated. This situation raises the question: where is mixed LLW going? Generators may be finding ways to treat some of their stored mixed LLW so that it is no longer a mixed LLW. However, it is also possible that some mixed LLW is slipping through waste brokers and processors, and is illegally entering nonqualified disposal facilities.

A primary problem is that some EPA regulations that apply to mixed LLW cannot be met (i.e., its land disposal restriction regulations). Many of the hazardous constituents in mixed LLW are banned from land disposal until they meet specific treatment standards. However, no offsite treatment facilities have been developed. Two examples of mixed LLWs for which no treatment capacity is available are organic chemicals and chlorofluorocarbon (CFC) solvents and sludges used in cleaning clothing, tools, and equipment. Furthermore, EPA developed its treatment standards based on hazardous waste only, not radioactive waste; therefore some of the standards are inadequate, inappropriate, or both. The NRC, EPA, and the Department of Energy (DOE) may wish to consider providing grant monies for researching treatment options and developing treatment facilities for these problem wastes.

A generator of mixed LLW for which no treatment capacity is available has no viable legal option for managing its waste. Even storage is illegal because of storage prohibitions. Generators, therefore, can stop producing the waste (which can mean going out of business); they can illegally store the waste; or they can illegally dispose of the waste.

EPA and NRC will have to decide how generators are to manage mixed LLW, given the absence of treatment facilities (in some cases the absence of an appropriate treatment technology), and the prohibition on storage. One option would be for EPA to relax its storage prohibition on wastes for which no treatment capacity and/or no disposal capacity is available. In turn, generators would have an intermediate *legal* option until treatment capacity and disposal capacity are developed and available. EPA could rescind this provision if a generator failed to demonstrate good faith effort in developing these capacities.

Goals for Congressional Consideration

To address the questions of whether States will comply with the LLRWPAA and how the problems pertaining to mixed LLW regulation can be resolved, Congress may want to consider two goals:

---

[3] Public Law 94-573, Oct. 21, 1976.

- to encourage States and compacts to cooperate among themselves so that all States can safely manage their LLW after December 31, 1992; and
- to resolve regulatory problems concerning mixed LLW.

There are several policy options that Congress may wish to consider to reach these goals.

Policy Options

Goal 1: Encourage Cooperation Among States and Compacts to Ensure Disposal Capacity Availability

1. Amend the LLRWPAA to force States and compacts to consolidate their disposal facility development efforts
   Pros: Economies of scale would be gained.
   Cons: It was never an intention of Congress to prescribe a certain number of facilities.
   Setting limits on the number of facilities would usurp State rights.
   Political climate within new host States would be damaged and their progress stalled.
2. Hold a congressional oversight hearing to encourage States to reduce the number of disposal sites
   Pros: It would provide a forum for encouraging cooperative agreements.
   Cons: Delicate negotiations amongst States and/or compacts would be disrupted and agreements in progress could be potentially killed.
3. Take no Federal action, but individual Members of Congress would track the progress of their States
   Pros: This option conforms with the original intent of Congress and the States. Members of Congress could discuss the issue with their governors and facilitate negotiations.
   Cons: There is no guarantee that agreements would be reached.

Goal 2: Resolve Regulatory Problems Concerning Mixed LLW

1. Give sole regulatory jurisdiction to one agency (legislation necessary)
   Pros: Facilities would be operated more economically and efficiently.
   Cons: One agency may not be able to carry out adequately the basic mission of the other agency's regulations—their regulatory approaches are very different (similar concerns at the State level). If the NRC is granted sole jurisdiction, EPA may lose regulatory authority over DOE defense sites.
2. Maintain current dual regulatory jurisdiction (joint guidance necessary)
   Pros: Each agency would be able to uphold its regulatory approach.
   Cons: Given the slow progress made by the two agencies thus far to resolve their differences, this option would not be timely.
3. Give one agency the regulatory lead with concurrence required by the other agency (joint rulemaking necessary)
   Pros: Facilities would be operated more economically and efficiently, but to a lesser degree than Option 1.
   Cons: The lead agency may not be able to carry out adequately the basic mission of the other agency's regulations, as under Option 1.
4. Establish an active interagency task force with congressional oversight
   (joint rulemaking/joint guidance necessary)
   Pros: Compromises between the two agencies could be resolved more quickly than under Option 2. Congress, in its oversight role, could forward a tight schedule for resolving the problem of unattainable regulations, the possible conflicts and inconsistencies, and the areas where the agencies' regulations overlap and are duplicative. If legislation is needed, Congress will be better informed after the task force has investigated these issues.

Cons: As with other options, the question remains whether the issues will be resolved fast enough.

UNDERSTANDING LOW-LEVEL RADIOACTIVE WASTE

What Is Low-Level Radioactive Waste?

Low-level radioactive waste (LLW) is defined in the LLRWPA of 1980 and its 1985 amendments by what it is *not*, rather than by what it is. **LLW includes all radioactive waste that is not classified as spent fuel from commercial nuclear power plants, defense high-level radioactive waste from producing weapons, or uranium mill tailings (see box 4-A in ch. 4).** About 97 percent of all commercial LLW produces relatively low levels of radiation and heat; it requires no radiation shielding to protect workers or the surrounding community; and the radiation decays within less than 100 years to levels that the NRC finds not to pose an unacceptable risk to public health (Class A LLW). The remaining 3 percent of LLW requires shielding and can remain harmful for 300 to 500 years (Class B and Class C LLW). A small percentage of LLW is Greater-Than-Class C (GTCC) waste and is the responsibility of the Federal Government to dispose. Isolation of GTCC waste needs to be for a few hundred to a few thousand years (8).

From 3 to 10 percent of all LLW is also considered mixed LLW because it contains both radioactive and hazardous constituents. Mixed LLW may be generated in several ways. For example, medical diagnostic procedures use scintillation fluids that contain small amounts of radioactivity in toxic organic solvents (e.g., xylene and toluene). These solvents generally pose a greater chemical hazard than radioactive hazard. Another example might be a rag containing a solvent used by a power plant worker to clean a radioactively contaminated water pump. If the solvent is listed by EPA as hazardous and the pump is slightly radioactive, the rag would be a mixed LLW.

The principal generators of commercial LLW, including mixed LLW, are nuclear power plants, industries, and academic and medical institutions. (See table 4-1.)

How Much Waste Is Generated?

No one knows how much commercial LLW, including mixed LLW, is generated in the United States; no comprehensive national survey has ever been conducted. Instead, records are kept of the LLW volumes shipped for disposal. Not all LLW generated, however, is disposed; extensive waste minimization practices and treatment practices result in a significant reduction in waste volumes. Table 1-1 lists the LLW volumes shipped by the nine compact regions and the seven unaffiliated States (plus the District of Columbia and Puerto Rico) in 1988; the total volume was about 1,440,000 cubic feet. Since no disposal sites exist for mixed LLW, these shipment figures include no mixed LLW. However, based on State and industry ad hoc surveys, it is estimated that mixed LLW would increase the national volume of nonmixed LLW by 3 to 10 percent.

The 1,440,000 cubic feet of commercial LLW shipped to disposal sites in 1988 would fill 390 tractor trailers, which if the trailers were lined up end-to-end would stretch over 3 miles.[4] For comparison, in 1988, hazardous waste, as regulated under RCRA and compacted (as is LLW) for disposal, would fill enough tractor trailers to stretch almost $1^1/_2$ times around the globe at the Equator (32,000 miles).[5] In contrast, radioactive spent fuel from operating commercial reactors accumulated in 1988, all of which is in storage, would only fill about half of a trailer.[6]

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[4] This analogy using tractor trailers demonstrates volumes only, not actual transportation scenarios, since tractor trailer weight limits would prohibit the transport of such heavy loads.

[5] As with the previous analogy, tractor trailers are used to demonstrate volume (not transportation scenarios) because of weight limitations. Unlike LLW, about 96 percent of RCRA hazardous waste is managed on site, with 4 percent shipped to commercial landfills.

[6] This analogy is also only used to demonstrate volume, not transportation scenarios, due to tractor trailer weight limitations. In addition, the heat associated with spent fuel would require much more space on a truck per unit of spent fuel.

Table 1-1—Commercial LLW Volumes Shipped for Disposal in 1988[a]

—	LLW volumes (cubic feet)
***Compacts*[b]**	
Southeast (**NC**, GA, FL, TN, AL, SC, MS, VA)	522,000
Appalachian (**PA**, WV, MD, DE)	172,000
Northwest (**WA**, ID, OR, UT, AK, HI, MT)	129,000
Central Midwest (**IL**, KY)	128,000
Southwestern (**CA**, SD, ND, AZ)	102,000
Midwest (**MI**, WI, IN, IA, OH, MN, MO)	96,000
Northeast (**CT**, NJ)	78,000
Central Interstate (**NE**, AR, LA, KS, OK)	71,000
Rocky Mountain (**CO**, NV, NM, WY)	4,000
***Unaffiliated States*[c]**	
New York[c]	65,000
Massachusetts[c]	47,000
Texas[c]	9,000
Vermont	7,000
Maine[c]	6,000
Rhode Island	1,000
District of Columbia	<1,000
New Hampshire[d]	<1,000
Puerto Rico	<1,000
Total	1,440,000

[a] No mixed LLW is included, since none was shipped for disposal after 1985.

[b] Host States that are operating, or scheduled to operate, a disposal facility are listed first.

[c] Unaffiliated States that are planning to develop a disposal facility.

[d] LLW volumes will increase once the Seabrook power plant is operational.

SOURCE: Data taken from tables prepared by EG&G Idaho in May 1989 for the U.S. Department of Energy, *DRAFT Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-006, Rev. 5, 1989.

A rough comparison by total weight indicates that in 1988 hazardous waste weighed 270 million tons, LLW weighed 36,000 tons, and spent fuel weighed 620 tons. Volume and weight figures are summarized in table 1-2, but it is important to note that they do not convey the relative health and environmental risks associated with each waste type.

Table 1-2—Waste Comparisons[a] for 1988

Waste type	Volume (cubic feet)	Weight (tons)
Hazardous waste[b]	13,000,000,000	270,000,000
LLW[c]	1,440,000	36,000
Spent fuel	1,800	620

[a] These comparisons do not illustrate the relative risks associated with each waste type, only the volume and weight of each.

[b] About 96 percent of this waste is managed onsite, with 4 percent shipped to commercial landfills.

[c] Commercial, nonmixed LLW. As with hazardous waste, a very high percentage of utility LLW is treated onsite, greatly reducing that shipped for disposal.

SOURCE: Office of Technology Assessment, 1989.

How Do the Risks of LLW Compare With Other Waste Types?

Regarding wastes (e.g., radioactive waste, hazardous waste) generated in our society, spent fuel from nuclear reactors and high-level waste from producing nuclear weapons most likely present the greatest risk to human health and the environment. EPA has determined that spent fuel and high-level waste must remain contained for at least 10,000 years.[7] The average concentration of spent fuel radioactivity is around 200,000 curies per cubic foot (8).

In contrast, the NRC has determined that LLW must remain contained for 100 to 500 years after site closure[8], while its average concentration of radioactivity is 0.1 curies per cubic foot (8). A containment period similar to the NRC periods does not exist for EPA-regulated hazardous waste packaging. The EPA does, however, require that no migration of hazardous constituents occur during the post-closure care period. This period is 30 years, but it can be shortened or extended depending on results from site monitoring. Unlike radioactive waste, however, the toxicity of some hazardous waste does not significantly decrease with time.

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[7] This 10,000-year standard was part of a larger set of standards, some of which were remanded by the First Circuit Court of Appeals in Boston in July 1987. The 10,000-year standard was not specifically remanded, however, EPA decided to reanalyze it and plans to promulgate a new set of standards.

[8] NRC LLW regulations are based on the stability of the waste and on the stability of the disposal site to protect a disposal site inadvertent intruder from receiving excess radiation exposure. The regulations establish three classes of LLW: Class A waste (the least radioactive), Class B, and Class C (the most radioactive). Concentration limits for radionuclides are set for the different classes of LLW. These limits are based on the relationship between a few factors: the half-lives of the radionuclides in the waste, the types of radiation emitted, and potential pathways to human exposure. During an institutional control period that follows site closure and lasts up to 100 years, the site is monitored and maintained. The NRC sets the concentration of radionuclides in Class A waste so that during the institutional control period, the radionuclides will decay to levels that the NRC determines will not pose an unacceptable risk to public health and safety, therefore, will not harm a hypothetical intruder digging into the waste after this period. Class B and Class C waste must be packaged in containers that will retain their structural integrity for 300 years, due to the allowed concentration of radionuclides in them. In addition, Class C waste must be deeply buried or have an intruder barrier, such as a concrete cover, to divert intruders for up to 500 years (10 CFR Part 61; see ch. 3).

It is very difficult to compare the risks from LLW to risks from hazardous waste. In many cases these two wastes behave inconsistently in the environment and their health effects may be uncertain. Furthermore, research in risk analysis has been conducted by different experts and little has been done to compare the findings. Mixed LLW further complicates the issue. Both the hazardous constituent and the radioactive constituent in a mixed LLW can vary greatly in the level of toxicity. **Research has done little to analyze the potential synergistic effects of the constituents of mixed LLW on the environment and on humans** (see ch. 4).

Similarities can also be noted between these waste types. With spent fuel, LLW, mixed LLW, and hazardous waste, the focus is on isolating them to minimize migration of their radioactive and/or hazardous constituents, thereby minimizing the risk of environmental contamination and human exposure. Furthermore, the duration of hazard associated with spent fuel and with some LLW, including mixed LLW, and hazardous waste is high (e.g., Class C nonmixed LLW, hazardous waste such as synthetic organics and heavy metals, and mixed LLW that is a combination of these two wastes). Likewise, the duration of hazard can be low for both LLW, including mixed LLW, and hazardous waste (e.g., Class A nonmixed LLW, hazardous waste that is biodegradable, and mixed LLW that is a combination of these two wastes). **Health effects from LLW, including mixed LLW, and hazardous waste are all difficult to estimate for low exposures and absorbed doses.**

Who Regulates Commercial LLW?

The NRC, under the Atomic Energy Act (AEA) of 1954[9], as amended, regulates the management of all commercial LLW unless a State has obtained Agreement State status under Section 274 of the AEA.[10]

The EPA or an authorized State agency regulates mixed LLW in conjunction with the NRC or an Agreement State. NRC or an Agreement State would regulate a mixed LLW facility with respect to the radioactive constituents, while the EPA or a State agency with mixed waste authorization would regulate the facility with respect to the hazardous constituents.

The NRC and the Department of Transportation (DOT) have a Memorandum of Understanding (MOU) regarding the transportation of LLW. Under the MOU, the DOT is responsible for regulating safety in transporting all hazardous materials, including radioactive materials, and the NRC is responsible for regulating safety in receipt, possession, use, and transfer of these materials.[11] The NRC also reviews and approves or rejects package designs for high concentration low-level radioactive materials. The term radioactive materials is defined to include radioactive wastes.

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[9] 68 Stat. 919, 1954.

[10] To become an Agreement State, a State must demonstrate to the NRC that the State's regulations are compatible. (In some cases, an Agreement State may establish regulations that are more restrictive than the NRC's regulations.) If this is demonstrated, the State may regulate the use of radioactive materials, except those used in the operation of nuclear power plants, which are still licensed and inspected by the NRC. There are 29 States that have received Agreement State status. A State can also receive limited Agreement State status. For example, a State may choose to regulate LLW disposal facilities but not treatment facilities. In States that have Agreement State status for LLW disposal, the disposal facility would be regulated by that State's regulatory authority (e.g., the Department of Environmental Control, Department of Environmental Resources).

[11] Refer to 49 CFR Parts 100-199 and 10 CFR Part 71 for more detail on the MOU.

MAJOR FINDINGS

Management Trends

Increased Use of Waste Minimization and Treatment Techniques

To reduce waste volume, costs, and risks, LLW generators employ a wide range of techniques to minimize and treat waste. Since 1980, these techniques have been major factors responsible for cutting LLW volumes by 55 percent.

Waste minimization techniques include material substitution, i.e., the use, whenever possible, of nonradioactive material rather than radioactive material, and operational practices that prevent materials from becoming contaminated. One industry representative believes that these minimization techniques have been used to the fullest extent practicable and that they will not increase the decline in waste volumes significantly.[12]

Treatment techniques,[13] as discussed in this report, generally focus on: 1) reducing the volume of LLW that must be shipped for disposal (e.g., waste sorting practices, decontamination, storage for decay practices, compaction, shredding, or incineration); and on 2) stabilizing wastes.

Once a waste is generated, decontamination and incineration appear to offer the greatest potential for reducing waste volumes. A commercial incinerator is scheduled to open in Oak Ridge, Tennessee, in February 1990; it will burn dry activated LLW which accounts for 50 percent of the nuclear power industry's LLW.

In addition to reducing volumes and thereby disposal costs, **treatment techniques can improve the stability of the waste form and, thereby, the performance of a disposal facility.** Specifically, a well-compacted, stabilized waste form can greatly reduce the threat of waste packages settling, a disposal unit cap failing, water infiltrating the waste, and radionuclides migrating offsite.

Treatment is a critical step in managing mixed LLW. **Since *no* offsite treatment or storage *facilities are available* for mixed LLW, generators try to the extent practicable to alter their practices in order to generate either exclusively radioactive waste or exclusively hazardous waste, for which management options are available.** Despite their efforts, mixed LLW is still generated, containing hazardous constituents that EPA bans from disposal until a particular treatment standard is met. Since no commercial treatment facility exists for these mixed LLWs, generators store them onsite. However, storage prohibitions apply to these wastes. This quandry concerning mixed waste treatment and storage is more thoroughly discussed below under "What Additional Concerns Apply to Mixed LLW?"

Support for New Disposal Technologies

More stabilized waste forms and more elaborate disposal technologies at future disposal sites will likely avoid the disposal problems (e.g., water infiltration into buried waste) that occurred at the three former commercial disposal sites—Maxey Flats, KY; Sheffield, IL; and West Valley, NY—all of which are now closed. At these sites waste packages were buried in excavated trenches—a technology called shallow-land burial. A variety of problems (see ch. 6), several of which related to poor operational practices rather than the disposal technology, resulted in radionuclides leaching from waste packages and migrating from the trench. According to NRC and State officials, the low concentration of radionuclides at each of the three sites' boundaries did not and does not pose an undue health risk to nearby residents. Dose models calculate the dose to be below NRC-permissible levels.

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[12] John Hsu, DuPont NEN, made this comment at the OTA Review Panel meeting, Washington, DC, Aug. 18, 1989.

[13] This broad use of the term "treatment" varies from EPA's definition. EPA does not support that the practices listed would necessarily be considered treatment for the hazardous constituents in mixed LLW but does contend that the practices may aid in the overall proper management of LLW, including mixed LLW.

Several alternative disposal technologies (see chl. 6) have been designed and are expected to be constructed in the next 3 to 5 years in several regions of the United States, particularly in humid regions. The main objectives of these new designs are to minimize water infiltration into buried LLW and to minimize subsequent migration of radionuclides via groundwater (10).

None of these new designs has been commercially built in the United States, but some have been demonstrated at DOE defense sites and some have been constructed and operated in Europe. Although there is limited U.S. data on the long-term performance of these technologies, **it appears that no significant technical advancements are necessary for these technologies to be developed commercially.**

Continuing long-term demonstration projects to test disposal facility caps may help in minimizing water infiltration, since the cap is the major barrier between the waste and precipitation. By including a monitoring point in the lower portion of the multilayered cap of the facility, site operators could detect water infiltration before the water comes in contact with the waste. A mechanism for collecting water and draining the water off of the cap could be included in the design.

Site-specific designs, appropriate construction, and comprehensive short- and long-term management of a LLW disposal facility are just as important as the particular disposal technology chosen. More elaborate designs, if poorly constructed or managed, may not provide more long-term waste isolation than a less elaborate facility that is well-constructed and well-managed. Quality control is critical to reducing human error and improving the short- and long-term performance of the site.

Increased Public Involvement

In most States designated to host a new LLW disposal facility, **local citizens and public interest groups have taken an active role in shaping the State's LLW disposal legislation and regulations; this role is likely to grow stronger in the future.**

An overriding concern of these individuals and groups is whether they can trust the disposal site operator. The public is frequently confronted with news stories of waste disposal problems, including water contamination at hazardous waste landfills, illegal dump sites, and Federal facilities (e.g., DOE weapons complexes). As a result, some citizens and public interest groups take a strong "not-in-my-backyard" stance when it comes to siting a waste disposal facility.

Some citizens and public interest groups want more access to the decisionmaker (i.e., an official that will decide where the facility will be located and how it will be designed). Recognizing this desire, the host States that are far along in developing a disposal facility have extensive public participation programs (see ch. 2). The environmental groups and citizen advisory committees in these States have largely influenced the overall LLW disposal site development process.[14] For example, in some States these groups have helped to determine the weighting factors for screening prospective regions within the State.[15]

Some public interest groups and citizen advisory committees have also contributed to the States' analyses of disposal technologies and disposal site requirements. These groups' disposal requirements are generally more conservative and more prescriptive than the standard conceptual designs. Also, their requirements often go beyond disposal facility features to include components of a comprehensive disposal system. For example, some public interest groups in Pennsylvania have argued that a facility should have "a zero release capacity" goal, i.e., that if any radioactivity above background level is detected offsite, the disposal facility operator must take action to identify and abate the release. This goal is much more stringent than the NRC regulation that the annual dose to a member of the public not exceed 25 millirems[16] of radiation to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ (10 CFR Part 61). Furthermore, this requirement must be met during the operational and long-term care period. Long-term care is defined in Pennsylvania as the "hazardous life" of the waste.[17] According to NRC regulations, the site operator must have its site secured and monitored after its operating period, but custodial institutional controls may not be relied on for more than 100 years (10 CFR Part 61).[18] However, due to the hazardous life of some radioactive waste and the hazardous life of mixed LLW, Pennsylvania is requiring as a precaution a long-term care period that would extend much longer than 100 years.

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[14] Once a disposal site is chosen, new local public interest groups may become involved because they will then see themselves as stakeholders in the process.

[15] A State is screened to identify regions that will be excluded from further consideration as a disposal site because they do not meet certain criteria.

Certain public interest groups in some States have required that the disposal facility operator be more aggressive in ensuring that the package manifest[19] accurately describes the contents of the package. States, in turn, are investigating methods of physically sampling and testing the waste without unacceptably exposing the worker.

Some host States are giving more control over their disposal facility to the host community. For example, the host community selects local inspectors to oversee the site. These inspectors have the power to shut down the facility if practices are out of compliance. In most States, the host community will also receive grants to conduct an independent assessment of the site.

Host States have created compensation packages for local host communities. These packages include assistance to local citizens, including financial incentives. Grants and scholarships are also available in some States to buy school equipment and to support science students. Finally, some host States guarantee local citizens' property values.

The role that public interest groups and citizen advisory committees have played to determine acceptable disposal designs, to develop a comprehensive disposal system, and to assure local control and compensation for local host communities could be precedent-setting with respect to other waste disposal facilities (e.g., those operated by DOE).

Major Issues

Will States Comply With the LLRWPAA?

About a dozen LLW disposal facilities are slated for development (see figure 1-1). It is impossible to know the exact number of sites that actually will be developed. While less than the dozen planned sites could easily handle the total volume of the Nation's LLW, **it is questionable whether all States and compacts that do *not* develop their own disposal facilities will be able to manage their own waste or reach an agreement with a sited State or compact when they lose access to the three operating sites on January 1, 1993.[20]**

States and compacts could reach agreements to cooperate in their management of LLW. An

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[16] A rem is a standard unit of measurement of the radiation imparted to biological systems by radioactive material. Rem is an acronym for "roentgen equivalent man." Rem is the unit used to measure equivalent dose—the biological effect of an absorbed dose. For comparison, the average annual whole body dose in the United States is about 300 millirems, of which about 50 percent is from natural background (see ch. 4). A millirem is a one-thousandth of a rem (10^{-3}).

[17] "Hazardous life" is defined in Pennsylvania as the maximum permissible concentration as defined in Federal regulation or as defined by the State. Pennsylvania defines hazardous life as the time required before an area can be released for unrestricted use. An analysis would be conducted that calculates the effect all possible pathways of exposure to determine the total exposure at a given time. Pennsylvania will have to determine that this total exposure level is at background level before deciding that the hazardous life has expired.

[18] The NRC, however, has no prohibition on States choosing a longer institutional care period.

[19] The NRC, EPA, and DOT require that a manifest document describes in detail the contents of a waste package and is affixed to a package before it is transported to a waste processing facility or to a disposal site.

[20] Under the LLRWPAA, States and compacts hosting a facility are not obligated to cooperate with other States and compacts.

agreement could involve a State or compact paying another State or compact to take its waste or involve States and compacts trading waste types or waste services. For example, the Governors of Maine and Vermont are negotiating with the Governor of Texas to have Texas take their waste. Texas has always planned to develop its own site, and there has been some question as to the legality of a single State excluding other States from using its facility (7). If Texas accepts Maine's and Vermont's waste (which is low in volume—see table 1-1) and forms a new compact, and if Congress consents to the compact, this question of exclusion rights would no longer be relevant.

A trade agreement could involve a compact deciding to trade its mixed LLW for another compact's Class C LLW.[21] A compact or State may also decide to develop a multiregional LLW treatment complex and trade these services for another State or compact to dispose of its waste. There may be great advantages for States and compacts to cooperate in such ways. Equity in sharing the responsibility for LLW could still be realized while treatment or disposal facility development costs could be saved. One disadvantage of this approach may be States' concern about the increase in liability associated with the increase in waste volumes. No State is currently planning to trade waste services with another State.

It is hard to predict whether States and compacts without access to a site will be successful at making these types of cooperative agreements or develop a way to manage their own LLW after the operating disposal sites close. States and compacts could have disposal facilities operational for their non-mixed radioactive LLW, but not for their mixed LLW, and eventually have to take title to and possession of the waste. If the State fails to take possession of the waste, it would eventually be liable for all damages incurred by the waste generator.

The next milestone for the States and compacts is to file a license application for a disposal facility by January 1, 1990, or to have their Governors certify to the NRC that they will have the capability to manage all their LLW by December 31, 1992. This 1990 milestone can be met and yet progress toward planning for post-1992 may be limited because earlier milestones are easier to meet than later ones.

How Will a Further Drop in Waste Volume Affect Disposal and Treatment Costs?

One factor that has made the development of multiple disposal sites difficult is shrinking LLW volumes. The nationwide LLW volumes have declined by about 55 percent in the last 9 years (see figure 4-4 in ch. 4) and could decline significantly more over the next few years. The past drop in volumes has been largely driven by costs related to implementing the 1982 LLW disposal regulations (10 CFR Part 61) and cost surcharges established in the LLRWPAA. A future drop in volumes will be driven by future LLRWPAA surcharges and costs associated with more elaborate disposal designs for facilities constructed to hold smaller waste volumes.

Many of the costs associated with developing a facility are fixed (e.g., State screening operations, site characterization, licensing, monitoring program, compensation packages to host community, and financial assurances). Therefore, costs per unit volume will increase with facilities designed to hold small waste volumes. While cost increases provide incentives for individual generators to reduce wastes, smaller volumes reduce economies of scale which drives up unit disposal costs. This scenario places more burden on small generators, e.g., medical and research facilities, than on large generators.

Some uncertainties make it difficult to predict how far future waste volumes will drop. First, radioactivity (measured in curies[22]) is also a determinant of disposal cost. Site operators may decide to place even greater emphasis on radioactivity, than is currently done, in determining disposal cost at future sites. They may make this decision because treatment practices have reduced volumes far more than generators have reduced radioactivity. A possible negative outcome of this approach would be that waste generators would have lowered incentives to use volume reduction techniques, which often result in a more stabilized waste form that is less likely to collapse or leach once disposed. The drop in future waste volumes could also be greater depending on the impact of below-regulatory concern (BRC) limits for the radiological component of a waste.[23] This impact may not happen depending on whether BRC waste is accepted at a municipal landfill or, in the case of mixed LLW, at a hazardous waste landfill.

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[21] In this example, a disposal provision would have to be made for Class C mixed LLW.

The phenomenon of increasing *unit* disposal costs due to decreasing waste volumes heightens if the Nation shifts from having three disposal sites to having a dozen or so, in which case *total* disposal costs may go up. LLW generators are required to use the disposal facility in their compact unless their compact has made an agreement with another State or compact. Therefore, in each of the nine compacts, the disposal site operator has a guaranteed market for LLW disposal. Unit disposal costs will probably vary significantly from one disposal facility to another, depending on the waste volume requiring disposal, the disposal technology used, and other site-specific conditions such as land values, State regulations, and local community compensation programs. For example, disposal in a below-grade vault for a compact region generating only 10,000 cubic feet of waste a year could be between $450 and $590 per cubic foot (3), while in a compact region generating 230,000 cubic feet of waste a year the cost could be between $50 and $56 per cubic foot for the same disposal design (3, 10). Yet generators in a particular State or compact cannot use a facility in another State or compact with a more economical disposal operation nor can a compact solicit out-of-State or out-of-compact customers to improve the economics of its facility unless the Board overseeing the compact approves of such an arrangement.

Until new LLW disposal facilities are operating and disposal costs stabilize, the trend of declining waste volumes will likely continue. By 1993, the trend in decreasing LLW volumes shipped for disposal should taper off, but by that time volume could drop 40 to 50 percent below 1988 levels. (See ch. 4 section on "Implications of Waste Minimization and Treatment Techniques on Future Waste Volumes.")

The same phenomenon is true for waste treatment. Some compacts are moving towards controlling the export and import of waste for treatment (e.g., waste decontamination, recycling, and compaction). They may believe that their regulations are stricter and require that all waste be processed within the compact. A compact may also choose to restrict waste from being imported for processing. The compact may not want to accept waste from a State that it believes may lose disposal capacity access, because it fears that it will have to keep the State's orphaned waste. By restricting the export and import of waste, however, competition to develop efficient treatment technologies will likely stall because of small waste volumes. **A decision by a compact to require its generators to use only its waste processing facility would run counter to the argument for State/compact cooperation. Likewise, closing compact treatment facilities to out-of-region States would oppose the argument for State/**

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[22] A curie is a common unit of measure of radioactivity that is based on the rate of radioactive decay. One curie describes the amount of radiation from 1 gram of radium for 1 second, or about 37 billion disintegrations per second. The abbreviation for curie is Ci.

[23] When a waste is determined by Federal or State regulations to be radioactively BRC, the concentration or quantities of radionuclides in the waste are so low that the waste can be disposed of in a nonradioactive waste site (e.g., a landfill) without posing an undue risk to public health and safety. The NRC and EPA are both working on setting limits for BRC waste. As of November 1989, the two agencies' limits were inconsistent; this will have to be resolved eventually because NRC's regulations that are set in a final rule must be consistent with EPA's final standard.

compact cooperation. The LLW Forum[24] passed a resolution on July 14, 1989 supporting the free movement of LLW and materials among regional compacts and unaffiliated States to treatment/processing facilities or to brokers.

What Additional Concerns Apply to Mixed LLW?

More immediate than any of the issues concerning nonmixed LLW management is the problem that no disposal facility or offsite storage or treatment facility for mixed LLW exists.

With respect to disposal, EPA regulations apply to hazardous waste landfills, while NRC regulations apply to LLW disposal facilities. A disposal facility for mixed LLW that incorporates both of these regulations, however, does not exist. Most generators, therefore, are using all available management techniques to alter their practices so that they generate either exclusively radioactive waste or exclusively hazardous waste. By doing so, disposal of the waste is possible. However, some practices that generate mixed LLW cannot be so altered and a LLW is generated that contains a hazardous constituent. As is discussed below, **the absence of treatment capacity, the absence of appropriate treatment technologies, storage prohibitions that cannot be met, and the absence of disposal capacity are serious problems that need to be addressed.**

Even without disposal facilities and offsite treatment and storage facilities, **ad hoc surveys indicate that the cumulative onsite storage volume of mixed LLW is holding steady for the majority of generators when it should be increasing (6). This situation raises the question: where is mixed LLW going?** Generators may be finding ways to treat some of their stored mixed LLW so that it is either exclusively radioactive or exclusively hazardous and, thereby, dispose of it legally. **However, it is also possible that mixed LLW is slipping through waste brokers and processors and illegally entering nonqualified disposal facilities.** Since waste packages are only visually spot-checked and scanned for radioactivity levels, it is possible that mixed LLW is entering the disposal sites *undetected*. Thus far, ad hoc State and industry surveys have neither supported nor refuted this speculation (6).

In passing the LLRWPAA, Congress did not give regulatory authority for mixed LLW to only the NRC or only EPA. Therefore, the NRC, under the Atomic Energy Act (AEA), and the EPA, under the Resource Conservation and Recovery Act (RCRA), have joint jurisdiction over mixed LLW. **Several States and compacts, particularly those in dry regions, believe that this dual regulatory system is technically unnecessary and burdensome.** NRC regulations are site-performance-based, meaning that the site as a whole has to meet certain objectives. NRC expects radionuclides to leach from the waste eventually, but at such a slow rate that no appreciable amount will ever reach the site boundary. EPA regulations are much more prescriptive in that they require certain features to be included in all disposal designs. For example, an EPA-permitted hazardous waste landfill must have double liners and a leachate collection system unless the permittee can demonstrate that *no* migration of any hazardous constituents into the groundwater or surface water will occur at any future time (40 CFR Part 264). It may be quite difficult to prove that *no* migration will occur. States particularly in regions with little rainfall, deep groundwater, and long groundwater time-of-travel argue that the EPA-required design features are unnecessary. Nonetheless, one such State, Texas, has decided to design its mixed LLW disposal unit with these features in order to comply with EPA regulations.

Some other States and compacts, particularly those in humid regions, believe that the two agencies' regulations complement each other and, if used together, would provide for the most technically suitable mixed LLW disposal facilities. Their designs currently include EPA-required features and NRC site performance requirements. For example, double liners and a leachate collection system would be included while worker exposure would be limited and the site would be environmentally monitored and secured from human intrusion for 100 years.

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[24] The LLW Forum is an association of representatives of States and compacts with the goal to facilitate implementation of the LLRWPA and LLRWPAA.

Regulations That Are Currently Unattainable—As noted, many of the hazardous constituents in mixed LLW are banned from land disposal until they meet specific treatment standards. However, no offsite treatment facilities have been developed, aside from an energy recovery facility burning BRC[25] scintillation fluids in Florida. **Two examples of mixed LLWs for which no treatment capacity is available are organic chemicals and chlorofluorocarbon (CFC) solvents and sludges used in cleaning clothing, tools, and equipment (6). Waste oil may also become a problem.** (Some States have listed waste oil as a hazardous waste, however, it is not hazardous under Federal law. A lawsuit has required EPA to consider whether waste oil should be listed as a hazardous waste, and EPA expects to make this determination in late 1989. If waste oil is found to be hazardous, the volume estimates of mixed LLW will rise dramatically.)

If treatment capacity is to be developed commercially for these wastes, generators of "like" wastes will have to group together and pressure the waste treatment industry to develop the necessary treatment facilities. However, for at least five reasons, the industry is reluctant to develop mixed LLW facilities. First is lack of data. Without a national survey on mixed LLW volumes and types, industry will have difficulty meeting market needs. Second is the possibility that compacts could attempt to restrict the import and export of waste for treatment, thereby limiting waste volumes and making the development of a treatment facility economically unviable. Third is the long licensing period expected for receiving a permit to operate such a facility. Fourth is the reluctance of facility operators to contaminate the internal mechanisms of their machinery with radioactivity. Fifth, is the opposition of some public interest groups to siting such facilities.

Certain mixed LLW contains hazardous constituents for which EPA recommends incineration as the best demonstrated available technology. **Yet in developing hazardous waste standards, EPA did not consider possible radioactive constituents.** In the case of organic chemicals containing high concentrations of carbon-14 and tritium, no standard off-gas systems for incinerators would trap these radionuclides. To meet EPA's regulations, a generator of this waste would have to apply for a treatment standard variance. **No generator has found a technology in the research and development phase, much less available commercially, that can handle this type of mixed LLW. The NRC, EPA, and DOE may wish to consider providing grant monies for firms to research treatment options for these problem wastes.** In particular, monies within DOE's technical assistance program for States could be redirected to support this research.

A generator of mixed LLW for which no treatment capacity is available has two potential options for treating its waste. First, it can submit a "no migration" petition, for which a generator must demonstrate that disposal of this waste, without being treated first, will result in no migration. However, no such variance for mixed LLW has been granted to date. Second, a generator can apply for a case-by-case extension for 1 year, renewable for 1 year. To receive this extension, however, the generator must have a binding contract with a mixed LLW treatment facility operator ensuring that at the end of the extension period the waste will be treated to meet EPA's standards. Since no such treatment facility is operational or, to date, is even planned, this second option appears unfeasible.

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[25] The BRC limits set for these fluids were established by the NRC in 1981 [(46 *Federal Register* 16230, Mar. 11, 1981) 10 CFR Part 20.306]. They are not the same limits as those over which the NRC and EPA are in conflict; the conflicting limits are for more generic types of LLW.

The result of considering these "options" forces generators into ceasing the practice that produces the mixed LLW or into simply storing their waste. Storage, however, is prohibited for any period longer than that needed to accumulate enough volume to "facilitate proper recovery, treatment, and disposal" (40 CFR Part 268). Since no commercial treatment facility or disposal facility is available for these problem mixed LLWs, storage in all likelihood would not be allowed.[26] **Mixed LLW generators are, therefore, left with no options but to stop generating the waste or to ignore the storage prohibition.** Without a solution to this problem, States or EPA could prohibit generators from producing mixed LLW or to cease operation. Services provided by nuclear utilities, pharmaceutical manufacturers, and research and medical institutions could be crippled.

Possible Regulatory Conflicts and Inconsistencies—Most States and compacts agree that potential conflicts and inconsistencies may exist between the NRC and EPA in implementing both agencies' regulations on a site-specific basis. However, **it is unclear whether all of the conflicts and inconsistencies can be resolved within the existing regulatory framework.** One example of a possible conflict concerns worker exposure during waste sampling and testing to characterize a waste (e.g., to test its leachability) and to verify the contents of a waste package received by the disposal site operator. For characterization, EPA requires that a generator take a 100-gram sample to test a waste's leachability if the generator cannot verify that the waste is not hazardous based on his/her knowledge of the process that generated the waste. For this size sample for some mixed LLW, the NRC considers it dangerous to workers. To circumvent EPA's requirement, a generator has to apply for a waiver, which can take years to receive. EPA and NRC are working toward resolving this issue, but no final joint guidance has been established.[27]

With respect to waste verification, EPA requires that the treatment, storage, or disposal site operator verify the contents of a waste package by obtaining a detailed chemical and physical analysis of a representative sample of the waste (40 CFR Part 264). As is true for a generator, an operator need not verify the waste by sampling unless he/she is not certain of the contents based on a single process that generated the waste. In cases where several wastes are combined in one package (as is the case for routine waste from waste brokers and processors) or where the process that generated the waste has changed, the site operator may have to sample widely, conducting a detailed chemical and physical analysis on each sample. In contrast, the operator of a LLW disposal facility generally only visually checks packages and conducts no chemical assays on the waste. Once again, the issue is worker exposure; following NRC regulations, it has to be as low as is reasonably achievable. **If a disposal site operator verified all necessary packages as required by EPA, he/she could receive excessive exposure.**

Another possible inconsistency or conflict between the two agencies is in inspection and enforcement. For a storage site, EPA requires that the operator directly inspect containers on a weekly basis (40 CFR Part 264). Typically, the inspection is done visually to see if any containers are degrading. The NRC, in contrast, allows much of its storage inspection to be done remotely, using cameras and area radiation monitors. Again, **a worker could be subjected to excessive exposure if he/she visually moni-**

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[26] Storage prohibitions do not apply in States that have base RCRA authorization but have not yet received mixed waste authorization. Mixed waste is a provision under RCRA, and EPA is not responsible for regulating a particular provision during the period while the State is waiting to receive authorization for it. Therefore, during this interim period before a State is granted mixed waste authorization, the storage prohibition does not apply unless a State law establishes the prohibition. As of October 1989, nine States had mixed waste authorization: South Carolina, Washington, Tennessee, Colorado, Georgia, Kentucky, Utah, Ohio, and Minnesota.

[27] EPA and NRC have drafted a document entitled "Characterization Guidance" that addresses the sampling procedure.

tored stored mixed LLW on a weekly basis.[28] Furthermore, it is unclear how the agencies would procedurally arrange the inspection and enforcement of facilities, given their joint jurisdiction: Would a team of agency officials with representatives from both agencies inspect the facilities and enforce the requirements? Would enforcement actions against a generator be carried out by a joint-agency team?

Timing conflicts and inconsistencies between the development of EPA's regulations and the development of State/compact LLW disposal facilities are problematic for mixed LLW in some cases. For example, many States are planning to receive mixed waste authorization, which means that they, instead of EPA, will regulate mixed LLW. However, this authorization may not be granted in time for mixed LLW disposal units to be permitted consistent with State timetables for developing their LLW disposal facilities.

Regulatory Overlap and Duplication—The NRC and EPA may want to evaluate several areas where their regulations overlap and their efforts could be consolidated to regulate mixed LLW more effectively and efficiently. Overarching regulatory areas include generic procedures for determining inconsistencies between the AEA and RCRA and below-regulatory concern limits for specific wastes (e.g., waste oil[29] and CFC solvents and sludges). For waste package manifests, the two agencies could establish one set of requirements. For documentation of facility activities, the two agencies could streamline the licensing and permitting procedures so that only one set of procedures would have to be followed. Recordkeeping, in general, could also be conducted in a format that would meet both agencies' needs. The two agencies could also agree on a single set of financial assurance requirements. Finally, several areas concerning practices at the site could be simplified; these include design variance procedures, facility monitoring requirements, emergency preparedness and prevention requirements, post-closure failure scenarios, and remediation requirements.

Conclusion

The generation of some mixed LLW is unavoidable, even if generation practices are changed to the extent practicable. Of primary concern is the management of organic chemicals and CFCs.[30] EPA and NRC will have to decide how generators are to manage these wastes, given the absence of treatment facilities, in some cases the absence of an appropriate treatment technology, and the prohibitions on storage.

With these roadblocks, generators are left with three options. They can stop producing the waste; they can illegally store the waste; or they can illegally dispose of the waste. None of these "options" are ideal and two of them (to illegally store or illegally dispose of the waste) could lead to adverse environmental and/or adverse health effects.

POLICY OPTIONS

What can Congress do to make sure commercial low-level radioactive waste, including mixed LLW, is disposed of equitably among States, in an environmentally sound manner, and with administrative efficiency? To grapple with these questions and the specific problems reviewed above, Congress may want to consider two major goals. They are: 1) to encourage States and compacts to cooperate among themselves so that all States can safely manage their LLW after December 31, 1992, and 2) to resolve regulatory problems concerning mixed LLW. There are several options that Congress may wish to consider to reach these goals.

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[28] It is unclear whether EPA would allow all of this inspection to be conducted remotely. The NRC and EPA are developing guidance on this issue.

[29] BRC limits for the radioactivity in waste oil would only be relevant to national mixed LLW management if EPA determines that waste oil is hazardous. Even if EPA does not make this determination, the BRC limits would apply to States in which waste oil is listed as hazardous.

[30] As noted, if EPA finds waste oil to be a hazardous waste, mixed LLW volumes will rise dramatically because the available treatment practices for waste oil will result in a residue that will still be found to be a mixed LLW.

Goal 1: Encourage Cooperation Among States and Compacts To Ensure Disposal Capacity Availability

Option A: Amend the LLRWPAA To Force States and Compacts To Consolidate Their Disposal Facility Development Efforts

Some States (e.g., Michigan) favor Congress amending the LLRWPAA to limit the total number of disposal facilities to gain economies of scale. These States believe that with fewer facilities, more revenue could be collected at each facility to support a more rigorous regulatory oversight program and a financially sound liability fund.

For three main reasons, amending the LLRWPAA does not seem very viable. First, neither the LLRWPA of 1980 nor the 1985 amendments of LLRWPA intended to prescribe a certain number of disposal facilities for the Nation. States felt that they should have the latitude to negotiate among themselves and form workable compacts. Congress made this a central theme to both the LLRWPA and the LLRWPAA. In some cases a compact of two States resulted and in others a compact of eight States resulted. Some States decided to develop a facility for waste generated only within their borders. Not surprisingly, political factors, rather than economic ones, were generally the driving force in compact membership. Also, for some compacts, economy was not as critical as ensuring that the facility could be built to accommodate public concerns.

Second, setting limits on the number of LLW facilities would take away State rights—the very rights that the States, via the National Governors Association, asked Congress to include in drafting the LLRWPA of 1980 and the LLRWPAA of 1985. As is, the LLRWPAA neither discourages nor encourages States to change the terms of their compacts. States are free to negotiate, if they so desire, and to cooperate among themselves to manage and dispose of LLW. The balancing of political factors and economic factors is left to the States.

Third, by limiting the number of LLW disposal facilities now, the supportive political climate under which new facilities are being developed could be damaged. Some States and compacts have made great progress in developing these facilities (e.g., Texas, the Central Midwest Compact, and the Southwestern Compact), and this progress could halt abruptly. The communities that have agreed to host a disposal facility may fear that they would be forced to take a much greater volume of LLW from elsewhere. They may feel that the equity built into the LLRWPA and LLRWPAA was being challenged. If the States and compacts that have made the most progress in developing new disposal facilities were to stop their development, the Nation would be little closer than it was in 1980, when the LLRWPA passed, to having new LLW disposal facilities.

As of November 1989, the most vocal State, Michigan, that lobbied Congress to consider amending the LLRWPAA to limit the number of LLW disposal facilities, had dropped its case. Michigan received no endorsement from the States and compacts that are making good progress in developing disposal facilities. Nonetheless, as tougher LLRWPAA milestones approach, which States and compacts must meet, the amendment argument could be raised again.

Option B: Hold a Congressional Oversight Hearing To Encourage States To Reduce the Number of Disposal Sites

Through an oversight hearing, a congressional committee with jurisdiction would encourage States and compacts to cooperate among themselves to ensure that every State can safely manage its waste after December 31, 1992. States in favor of Option A would likely support this option.

A potential downside of such congressional action is that many States and compacts may not be in a position to discuss the delicate negotiations they are undertaking. The Governor of a host State that plans to build a disposal site for nonmixed LLW may be quietly negotiating with the Governor of a host State that plans to develop a disposal unit for mixed LLW. These Governors may be negotiating a trade—nonmixed LLW for mixed LLW and vice versa. **An oversight hearing may only agitate these negotiations. Furthermore, a hearing could panic potential host communities into rejecting their role.** All States that have made significant progress toward developing disposal capacity would likely be opposed to this option.

Option C: Take No Federal Action, But Individual Members of Congress Would Track the Progress of Their States

Alternatively, Congress would take no public action to reduce the number of disposal sites. Instead, individual Members of Congress could keep abreast of the progress their States are making to ensure that disposal capacity will be available. Members of Congress could discuss the issue with the Governors of their particular States, determine whether negotiations are proceeding, and determine how they can be quietly facilitated.

Goal 2: Resolve Regulatory Problems Concerning Mixed LLW

There is a range of policy options that could meet this goal. Four main options are presented here. As shown in figure 1-2, at one end of a spectrum, either the NRC or EPA may receive sole regulatory jurisdiction. At the other end, dual NRC-EPA jurisdiction as it now stands can continue. Between these two extremes are two other possibilities. All four options, with scenarios for implementation, are discussed below.

How any option would be implemented depends on whether the State in question has Agreement State status under the AEA or mixed waste authorization under RCRA, or both. Furthermore, to implement one option would require legislation, while for others only rulemaking and/or guidance would likely be required.

Option A: Give Sole Regulatory Jurisdiction to One Agency

Either NRC or EPA would be given sole jurisdiction for regulating mixed LLW. Sole jurisdiction would require legislation. Several groups (e.g., Edison Electric Institute, Utility Nuclear Waste and Transportation Program, Nuclear Management and Resources Council, Utility Solid Waste Activities Group, and some user groups of radioactive materials) have lobbied Congress to give the role to the NRC. They argue that the current dual regulatory system is duplicative, burdensome, and inconsistent (1, 2, 4). They believe that the regulations EPA applies to mixed LLW that are not included in NRC's regulatory framework could be added to the NRC framework and enforced by NRC.

Sole jurisdiction could also be given to EPA. Regulations that NRC applies to mixed LLW could be added to EPA's regulations and enforced by EPA. No group has supported this approach to date, however.[31] One reason is that mixed LLW was buried at LLW sites, until burial was no longer allowed, and the radioactive waste community became more familiar with NRC regulations than with EPA regulations. Furthermore, it was assumed that by regulating the radioactive portion of the waste, the hazardous portion would be regulated as well.

An advantage of sole regulatory jurisdiction is that from an administrative perspective mixed LLW disposal facilities, or special mixed LLW units at a larger facility for mainly nonmixed radioactive LLW, could be developed and operated more economically and efficiently. The disposal site developer/operator would have only one agency (whether at the State or Federal level) with whom it would have to coordinate. Furthermore, a waste generator, processor, and a disposal site developer/operator would no longer need two sets of manifest documents or two sets of reporting forms.

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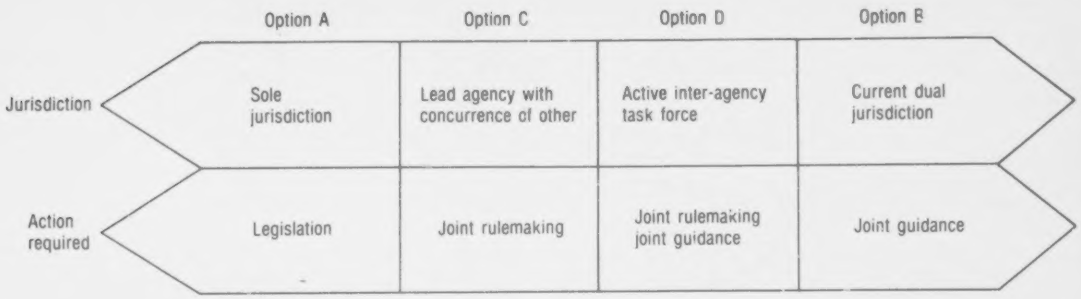
[31] If the environmental community (e.g., the Natural Resources Defense Council) had to choose between the NRC or the EPA for sole jurisdiction, it would favor the EPA. The environmental community, however, favors both agencies regulating mixed LLW.

Figure 1-2—A Spectrum of Policy Options for Mixed LLW Regulation



	Option A	Option C	Option D	Option B
Jurisdiction	Sole jurisdiction	Lead agency with concurrence of other	Active inter-agency task force	Current dual jurisdiction
Action required	Legislation	Joint rulemaking	Joint rulemaking joint guidance	Joint guidance

SOURCE: Office of Technology Assessment, 1989.

If the NRC is granted sole jurisdiction, mixed LLW generators and processors would need only a license from the NRC or, if located in an Agreement State, from the designated State agency to treat and store their waste. Generators would not have to receive a permit from EPA or, if the State is mixed waste authorized, the State designated agency. If a State had Agreement State status, the State agency with jurisdiction (e.g., Department of Nuclear Safety, Department of Health Services) by itself would regulate all mixed LLW management activities. If the EPA were to be granted sole jurisdiction, the designated agency in a State with mixed waste authorization would assume much of the regulatory role.[32]

A major disadvantage of shifting all Federal regulatory responsibility to one agency is that the one agency may not be able to carry out adequately the basic mission of the other agency's regulations. For example, if the NRC is granted sole regulatory responsibility, it may have trouble assuming EPA's regulatory philosophy of treating waste to the extent practicable and making waste as nonhazardous as possible before disposing of it. EPA holds this philosophy because many of the hazardous constituents EPA regulates can become very mobile in a disposal site and can migrate offsite via groundwater; organic chemicals are good examples. EPA has a long history of regulating these types of wastes and this expertise may not readily transfer to the NRC. The reverse would be true if EPA is granted sole regulatory responsibility. EPA may not be able to appropriately reflect the AEA's and NRC's philosophy. For example, it is unclear whether EPA would adopt NRC's concern about worker exposure being kept as low as is reasonably achievable and about the institutional control period at a mixed LLW disposal facility lasting up to 100 years.

Similar problems with respect to one State agency regulating mixed LLW could result. For example, assume that NRC is given sole regulatory authority and a particular State has Agreement State status; the authorized agency within that State may have no working knowledge of hazardous waste and be unable to effectively regulate mixed LLW from a hazardous waste perspective. Likewise, assume that EPA is given sole regulatory authority and a particular State has mixed waste authorization; the authorized State agency may have no working knowledge of radioactive waste and be unable to effectively regulate that part of the waste.

Another disadvantage of transferring all regulatory responsibility to the NRC would

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[32] EPA, as well, would have a role in regulating mixed LLW on issues that the State had not yet received jurisdiction. For example, a State could have mixed waste authorization and yet not have received responsibility for enforcing new standards that had recently been issued by EPA that deal with some aspect of mixed LLW. EPA is constantly issuing new regulations, and RCRA-authorized States have some time to become responsible for them.

be the potential loss of EPA's regulation of hazardous waste at DOE defense sites. To date, DOE sites are independently regulated only for their hazardous materials and subsequent wastes that are produced. A large constituency, including several public interest groups (e.g., the Natural Resources Defense Council), feels strongly that EPA regulatory oversight of waste management activities is necessary for adequate environmental protection, including the restoration of contaminated areas at DOE sites. **Removing EPA from regulating commercial mixed LLW would raise the question of whether EPA should be removed from regulating defense mixed waste as well.**

For the above reasons, it appears likely that the expertise of both agencies will be needed to continue regulating mixed waste. Environmental organizations (e.g., the Natural Resources Defense Council) oppose either agency being given sole regulatory jurisdiction.

Option B: Maintain Current Dual Regulatory Jurisdiction

The present dual jurisdiction of NRC and EPA can continue, along with the schedule on which the two agencies are working to resolve implementation issues relating to the dual regulation of mixed LLW. Legislation would not be required to implement this option. Most likely only joint guidance would be needed.

Under this option, in a State with only Agreement State status, a State agency would regulate the radioactive portion of the mixed LLW while the EPA would regulate the hazardous portion. In a State with only mixed waste authorization, a State agency would regulate the hazardous portion of the waste while the NRC would regulate the radioactive portion. In a State with both of these State authorities, the State agencies would regulate both the radioactive and hazardous components of the waste. As described in Option A, the range of regulatory possibilities, considering both Federal and State jurisdiction, are numerous and can greatly complicate policy decisions.

Since the passage of the LLRWPAA in 1985, the EPA and the NRC have only developed three guidances/guidelines. There are several areas of potential regulatory conflict and inconsistency, areas where regulations are unattainable, and areas where the regulations are duplicative. **It is imperative for safely managing mixed LLW that the current schedule of resolution between the two agencies be greatly accelerated.** Timely action is particularly needed for mixed organic chemicals and CFCs that may be being illegally stored for lack of treatment and disposal capacity. No constituencies, including public interest groups or industry, have supported Option B.

Option C: Give One Agency the Regulatory Lead With Concurrence Required by the Other Agency

One option between the two extremes is for one agency to take the regulatory lead, but only with the other agency's concurrence on regulatory issues. Joint rulemaking would most likely be required to implement this option.

An advantage of this option, as with the option of one agency having sole regulatory jurisdiction, is that mixed LLW would be more economically and efficiently regulated. Coordinating with the lead responsible State or Federal regulatory agency would be easier for all waste management activities than coordinating with two agencies at all times.

As with the sole regulatory jurisdiction option, **the major disadvantage of Option C, but to a lesser degree, would be the question of whether the lead agency could appropriately carry out the tenor of the other agency's regulations.** Even with concurrence by the supporting agency, it is difficult to ensure that its regulations would be implemented thoroughly. Furthermore, as with sole jurisdiction, if a State agency must take the lead to regulate mixed LLW, the agency may be ill-equipped to carry out dual roles with equal expertise. Another disadvantage is that the concurrence requirement could greatly impede resolution of the various regulatory problems concerning mixed LLW.

Option C has been neither supported nor dismissed by public interest groups and various industries. However, environmental organizations are against designating the NRC as the lead agency.

Option D: Establish an Active Interagency Task Force With Congressional Oversight

Another option between Option A and Option B is for an active interagency task force to resolve problems concerning regulation of mixed LLW. The current NRC-EPA Interface Council, which was formed to address mutual concerns, would be expanded, or a new task force would be formed with members from both agencies. **Congress, in its agency oversight capacity, would request such a task force to develop joint rulemaking or joint guidance on mixed LLW issues where compromises between the two agencies are needed.**

Task forces have been used effectively in other cases of overlapping Federal regulatory jurisdiction. For example, the Mine Safety and Health Administration has overlapping jurisdiction with the Occupational, Safety, and Health Administration in developing health and safety standards for employees in the mining industry. The two agencies formed an interagency agreement, including a provision to develop joint rulemaking and cooperative training.[33] Likewise, the Food and Drug Administration, within the U.S. Department of Agriculture, and EPA have an overlap on regulating biotechnology products. A Biotechnology Science Coordinating Committee was established, consisting of members from both agencies, to regulate these products (7).

Congress could forward a tight schedule, containing milestones for resolving possible conflicts and inconsistencies, to the task force. Joint rulemaking or joint guidance, in fact, could be established for all of the following issues:

- regulations that are currently unattainable:
  - —certain treatment standards,
  - —storage prohibitions;
- possible regulatory conflicts and inconsistencies:
  - —waste sampling and testing,
  - —facility inspection and enforcement,
  - —timing conflict between EPA location standards and LLW disposal siting efforts,
  - —timing conflict between States being granted mixed waste authorization and States' schedules in developing LLW disposal facilities;
- regulatory overlap and duplication:
  - —procedures for determining inconsistencies between AEA and RCRA,
  - —BRC limits for specific wastes,
  - —facility design variance procedures,
  - —waste package manifest requirements,
  - —licensing and permitting procedures,
  - —recordkeeping,
  - —financial assurance requirements,
  - —facility monitoring requirements,
  - —emergency preparedness and prevention requirements,
  - —post-closure failure scenarios,
  - —remediation.

In addition to developing rulemaking and guidances on the issues above, **Congress could request that the task force report on additional areas where rulemaking or guidance is needed.** This task force could decide that all the issues are resolvable through joint rulemaking or joint guidance, or it could decide that legislation is needed. **If legislation is needed, Congress will be better informed after the task force makes its recommendations than it is now to determine which issues need to be resolved by law.**

Some compacts (e.g., Central Interstate) and public interest groups support this option as a practical approach to regulating mixed LLW. Opposing this option are the electric utility industry and some user groups of radioactive materials. These opposition groups are more familiar with NRC regulations than with EPA regulations and would prefer reporting to one agency—the NRC. However, because of the disadvantages discussed under Option A (e.g., the difficulty of *one* agency enforcing *both* sets of regulations and the precedent that would be set for DOE defense waste regulation if the NRC were granted sole jurisdiction over mixed waste), it appears that the expertise of both agencies is needed. Chairman Carr of the NRC has had discussions with EPA Administrator, William Reilly, on the problems concerning mixed waste regulation. The agencies have made little progress, however, in resolving these problems. No legal impediment is keeping the NRC and EPA from expanding their Interface Council or from creating a new task force. There is, however, no evidence that the agencies plan such action.

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[33] 44 Federal Register 22827 (Apr. 17, 1979).

Issue Requiring Prompt Resolution

It is imperative that mixed waste regulations that are currently unattainable be addressed immediately so that waste generators are left with an option for managing their mixed LLW. Today these generators face the choice of going out of business (if they have to stop producing the waste), illegally storing the waste, or illegally disposing of it.

To address this problem, Congress could encourage EPA to allow generators/operators to store a particular waste if no treatment capacity and/or no disposal capacity is available. In other words, storage would be allowed only if it is not being used in lieu of disposal. **This action would give mixed LLW generators an intermediate option until treatment capacity and disposal capacity are developed and available.**

EPA could require that generators demonstrate their diligence to ensure that these facilities are developed as a condition for permitting mixed LLW storage. EPA would have authority to stop waste storage if a generator fails to demonstrate progress. An advantage of this approach is that by generators applying for a storage permit, EPA would have a record as to what types and volumes of mixed LLW are being generated. EPA could use the data to better ensure that wastes are not being illegally disposed. The waste treatment industry could use the data as a marketing tool to develop necessary waste treatment facilities.

Monies could be allocated within EPA, NRC, and DOE budgets to support entities (e.g., universities, national laboratories, and private companies) that are interested in researching and developing treatment technologies for mixed LLW. For example, monies could be redirected from the DOE technical assistance program established to support States' site development efforts. Particular attention could be given to treatment technologies for organic chemicals containing high concentrations of carbon-14 and tritium.

With congressional support, there may be a way for EPA to allow such intermediate storage when it issues its rule for treatment standards, established in the final third of listed hazardous wastes (due tc be issued in May 1990).

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Chapter 2

Federal Legislation and State and Compact Response

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Chapter 2

Federal Legislation and State and Compact Response

FEDERAL LEGISLATION

Low-Level Radioactive Waste Policy Act of 1980

In the fall of 1979, a series of transportation and packaging incidents[1] prompted the Governors of the three States with operating commercial low-level radioactive waste (LLW) disposal facilities to take action to protect public health and safety. The Governors of Washington and Nevada temporarily closed their sites, and the Governor of South Carolina instituted a program to reduce by one-half the amount of waste disposed of at the site, which had received more than 80 percent of the Nation's waste during the preceding year.

All three existing sites—as well as three former commercial sites that were closed[2] for various licensing and environmental reasons (see ch. 6)—had been established by private LLW disposal companies and were operated without any formal interstate agreements governing waste acceptance. While the initial motivation behind the newly imposed disposal restrictions was to protect health and safety, the three States with sites, referred to as sited States or host States, were also signaling their unwillingness to continue to accept the entire country's LLW indefinitely.

Alarmed by the potential loss of all commercial LLW disposal capacity, several committees of the U.S. House of Representatives held hearings in November 1979 on future Federal LLW waste disposal policy. Initially, these committees considered adopting legislation that would have made commercial LLW disposal a Federal responsibility. Immediate congressional action of this type was opposed by the Governors of the three sited States, who testified in favor of allowing States an opportunity to examine alternatives to Federal disposal. Because Washington and Nevada had reopened their sites and, because the congressional session was nearly over, the committees agreed to defer consideration of LLW legislation until the following year.

During the next 3 months, a number of interested organizations established task forces or review groups to explore alternate ways to assure disposal capacity for commercial LLW. The Conservation Foundation formed a dialogue group on LLW in November 1979. The next month, the National Governors' Association (NGA) created an eight-Governor task force on LLW disposal. The same month, the Department of Energy (DOE) named a task force to deal with LLW issues and created a Program Review Committee to provide broad-based guidance to DOE's LLW management program. In February 1980, President Jimmy Carter established the State Planning Council to deal with all nuclear waste issues. All of these entities examined various ways to address the disposal of LLW, and, by the summer of 1980, all had agreed that a State-oriented solution was the best means of assuring new capacity.

A number of considerations supported a State rather than Federal solution. Chief among them was the concern that the new sites not pose a threat to public health and safety. States were convinced that they were better qualified than the Federal Government to assure the protection of their citizens and the environment. While subsequent revelations have confirmed that many Federal facilities have not taken adequate care of nuclear and hazardous materials in the past, many States—especially those with Federal facilities in their boundaries—were convinced even in 1980 that it was a sound environmental policy decision to give States the responsibility for providing for new commercial LLW disposal capacity. States wanted to be involved in decisions regarding siting, technology selection, operator choice, regulation, fee schedules, and public participation. State representatives believed that States had the political, technical, and economic resources to handle LLW disposal. For these reasons, State-oriented organizations such as the NGA, the National Conference of State Legislatures, and the State Planning Council all endorsed a State-oriented solution in the summer of 1980. The DOE LLW task force and Program Review Committee and the Conservation Foundation Dialogue

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[1] For example, in 1979, the Beatty, NV site was temporarily closed when a fire occurred in a truck carrying low-level radioactive waste and contaminated liquids leaked from the truck. Similar incidents occurred at the Richland, WA site in 1979, causing it to be temporarily shut down as well. Incidents included a shipment of cobalt leaking and a truck exceeding allowed weight limits.

[2] A LLW disposal facility in Maxey Flats, KY, operated from 1963 to 1977. In West Valley, NY a LLW facility operated from 1963 to 1975. Finally, a LLW facility operated in Sheffield, IL from 1967 to 1978.

Group also recommended that the States be given the lead role on this issue.

In August 1980, the NGA task force issued a 75-page report containing 17 recommendations (48). This report reflected in greater detail the sentiments of the other entities mentioned above. The principal findings of the report were:

- LLW could be managed most efficiently at the State level.
- Each State should be given the responsibility to provide for disposal capacity for the commercial waste generated within its borders.
- States should be encouraged to form regional compacts, since fewer than 50 sites were needed to dispose of the Nation's anticipated volume of commercial LLW.
- To foster compact formation, regional compacts should be allowed to exclude waste generated outside their borders after a specified date.

Interstate compacts requiring congressional approval were recommended as the preferred form of interstate agreement for several major reasons. First, States cannot customarily restrict the importation of waste to commercial facilities within their borders and to do so would violate the interstate commerce clause.[3] To exercise the exclusionary powers suggested in the Federal legislation would require consent by Congress. Thus, only interstate compacts would meet this requirement. Second, since interstate compacts are Federal law as well as State law, they have a permanence and enforceability that other forms of agreement lack. Since LLW waste sites are built to operate for several decades and most compacts anticipate establishing a series of LLW sites, it is advisable to have these facilities governed by statutes that cannot be as readily changed as other types of interstate agreements.

Given both the broad-based support for delegating responsibility for new disposal capacity to the States and the unanimous endorsement of the NGA, Congress ratified the Low-Level Radioactive Waste Policy Act (LLRWPA) in December 1980—just 13 months after the issue had first gained national attention. The legislation had three major provisions which were included in the NGA task force report:

- Each State was made responsible for providing for the availability of disposal capacity for the commercial waste generated within its borders.
- States were encouraged to form interstate compacts to collectively meet their obligation to provide disposal capacity.
- As an inducement to form compacts, States were encouraged to include authority to exclude LLW generated outside their borders in the compact legislation they adopted and submitted to Congress.

Following congressional action, States began discussions on creating regional compacts. Among the first compacts to be submitted to Congress were three that included the three existing host States —Washington, Nevada, and South Carolina. One of the prime motivations of these States in supporting the adoption of the LLRWPA was their desire to reduce the quantity of waste being shipped to their sites. Given that the 1980 Act invited regions to submit compacts with the authority to exclude out-of-region waste after January 1, 1986, the sited States quickly negotiated compacts with their neighbors and sent the proposals to Congress for ratification. The member States party to a compact with an existing site are referred to as sited States. States without access to a site also recognized the advantages of compacts and negotiated compacts as well. By late 1984, nearly 40 States had joined 7 compacts and submitted them to Congress. A detailed discussion of these compacts and how they evolved is provided below, under "State and Compact Response to Federal Legislation."

Low-Level Radioactive Waste Policy Amendments Act of 1985

Despite the progress in forming compacts, the prospect of the three sited States being able to exclude all out-of-region waste after January 1, 1986, caused the Senators and Representatives of States and compacts without access to a site to oppose granting congressional consent to the sited States' compacts. States and compacts without access to a site were unwilling to allow the sited States' compacts to pass Congress unless there were some assurances that the LLW from their States would continue to be accepted at the sited States' facilities until new sites were operating. The sited

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[3] The Commerce Clause is in the United States Constitution, Art. I, sec. 8, cl. 3. It states that "The Congress shall have Power. . .To regulate Commerce. . .among the several States. . ." Many cases have interpreted this clause, and in particular several have been concerned with a State's right to exclude waste generated in other States.

States for their part threatened to shut down their facilities altogether if their compacts were not adopted by Congress. This impasse continued until late 1984. Seven compacts were pending before Congress, but there was no prospect for approval.

With the January 1, 1986, exclusionary date less than 15 months away, some Members of Congress once again turned their attention to Federal LLW policy. While the 1986 date was perhaps mainly symbolic in value, key committee chairs recognized that the impasse over consent to the compacts represented a threat to the success of the LLRWPA of 1980. With an eye to breaking the deadlock, Representative Morris Udall of Arizona, Chair of the House Committee on Interior and Insular Affairs, introduced legislation in October 1984 amending the LLRWPA. Although the draft legislation was skeletal in nature, it did indicate to all interested parties—particularly the States and compacts—that Congress was intent on preserving the LLW system that had been established 4 years previously.

Less than 5 weeks after the introduction of the Udall bill, representatives of States and compacts held a series of meetings under the aegis of the NGA. The goal of the meetings was to negotiate a compromise between the sited States and compacts and the unaffiliated States[4] and compacts. Representatives of the States and compacts were convinced that they could achieve a satisfactory solution to the problem. Congress, for its part, was willing to accept the compromise developed by the States and compacts if it was acceptable to the key interested parties and if it promised to promote the goals of the 1980 LLRWPA.

Throughout 1985, States and compacts met frequently to discuss amendments to the LLRWPA. Representatives of other interests, including congressional staff, waste generators, site operators, insurance companies, and environmental groups also participated. The legislation eventually adopted by Congress in December 1985 largely reflected the concerns of the States and compacts. The legislation formed a compromise between States and compacts without access to a site and sited States and compacts. This compromise was needed to further progress in constructing new LLW disposal facilities. Since the legislation contained the compromise provisions endorsed by the States and compacts, Congress was also able to consent to the seven compacts that had been pending for several sessions. These seven compacts—the Northwest, the Rocky Mountain, the Central Interstate, the Central Midwest, the Midwest, the Southeast, and the Northeast compacts—were adopted as Title 2 of the 1985 Amendments. Subsequently, two other compacts—the Appalachian and the Southwestern—have received congressional consent.

The chief features of the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985 were a 7-year extension of the date by which the sited States could exclude waste outside their regional boundaries, coupled with a series of milestones and enforceable penalties to assure progress in establishing new facilities during the 7-year transition period.

Key Elements: Low-Level Radioactive Waste Policy Amendments Act of 1985

The LLRWPAA of 1985 establishes a set of incentives and conditions that allows access to existing disposal facilities through the end of 1992 (see table 2-1). Milestones and deadlines are established in the LLRWPAA to ensure that new disposal capacity is available to compacts without access to a site and to unaffiliated States until the early 1990s. Failure to meet the milestones can lead to the imposition of penalty surcharges and possibly to denial of access to the disposal sites.

Main features of the LLRWPAA include:

- a 7-year interim access period consisting of a 4-year transition period and a 3-year licensing period,
- disposal site volume limits and reactor volume allocations,
- escalating surcharges to encourage volume reduction and disposal facility development,
- milestones and deadlines for new disposal facility development,
- surcharge rebates to encourage disposal facility development, and
- penalties for failure to meet milestones.

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[4] States that do not belong to a compact are known as unaffiliated States.

Table 2-1—Milestones and Deadlines in the Low-Level Radioactive Waste Policy Amendments Act of 1985

Milestone		**Deadline**	
Requirement	Penalty	Requirement	Penalty
July 1, 1986 Each unaffiliated State must join a compact or indicate the intent to develop a site for LLW within the State.	2 x the surcharge ($20/cubic foot) for the period July 1, 1986, through Dec. 31, 1986 Access to existing disposal sites may be denied after Jan. 1, 1987.	***January 1, 1993*** Each compact without an operating facility and unaffiliated State must provide for the disposal of all applicable LLW, including mixed LLW generated within such State or compact region, or the rebate monies due the State may be returned to generators incrementally.	1/36 of the rebates collected for the period Jan. 1, 1990, through Dec. 31, 1992, returned to generators monthly with interest. Rebates to generators continue until Jan. 1, 1996, or until State provides for disposal.
January 1, 1988 Each compact without an operating disposal facility must identify a host State or select a facility developer and location--and must have developed a siting plan. Each unaffiliated State must also have developed a siting plan.	2 x the surcharge ($40/cubic foot) for the period Jan. 1, 1988, through June 30, 1988. 4 x the surcharge ($80/cubic foot) for the period July 1, 1988, through Dec. 31, 1988. Access to existing disposal sites may be denied after January 1, 1989.	***January 1, 1996*** Each compact without an operating facility and unaffiliated State must provide for the disposal of all applicable LLW, including mixed LLW, generated within the State or compact region, or each State must assume title, possession, and liability for the LLW generated within the State.	
January 1, 1990 Each compact without an operating facility and unaffiliated State must submit a complete LLW license application to operate a disposal facility, or the Governor of each State must provide a written certification to the NRC that the State will provide for storage or disposal of LLW generated after December 31, 1992.	Access to existing disposal sites may be denied after Jan. 1, 1990.		
January 1, 1992 Each compact without an operating facility and unaffiliated State must submit a complete license application to operate a LLW disposal facility.	3 x the surcharge ($120/cubic foot maximum) for the period Jan. 1, 1992, until complete application is filed or until Dec. 31, 1992.		

SOURCE: Afton Associates, 1989.

As a result of the LLRWPA of 1980, the LLRWPAA of 1985, and the subsequent compact consent legislation, there are now 9 compacts with a total membership of 43 States. Seven States are presently unaffiliated with a compact, as are the District of Columbia and the Commonwealth of Puerto Rico, both of which are given the same responsibilities as States under the Federal legislation. The State of Washington has decided to continue as the host State for the Northwest Compact and plans to continue using the existing LLW disposal site near Hanford, WA, as the region's disposal facility. The existing disposal facilities in Barnwell, SC, for the Southeast Compact and in Beatty, NV, for the Rocky Mountain Compact are scheduled to close on or before January 1, 1993. Prior to their closure, a new disposal facility is planned to be operational in each compact (i.e., in North Carolina and Colorado respectively).

Except for a compact's selection of a host State, all other major decisions regarding facility development and regulation are the responsibility of the host State or site operator, depending on host State requirements. As a result, most host States have devised unique approaches to siting that are tailored to address State-specific concerns. In many cases, the resultant State laws and regulations have been developed with extensive public input and are more stringent and comprehensive than Federal requirements. Because of this diversity of approaches and requirements, each host State's progress must be evaluated within the context of its individual requirements, procedures, and timetables.

STATE AND COMPACT RESPONSE TO FEDERAL LEGISLATION

The history of each compact's formation and the efforts of each compact and unaffiliated State to develop new LLW disposal facilities is traced below. Unique aspects of each compact's and State's siting program are highlighted, such as benefit packages and compensation measures that were particularly influenced by public input. Each compact and unaffiliated State is proceeding on different internal schedules for having disposal capacity available by the January 1, 1996, deadline.

Sited Compacts

Northwest Compact

Member States: Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington

Host State: Washington

The Richland, WA disposal site has operated since 1965. Through the work of the Radioactive Waste Committee of the Western Interstate Energy Board, Washington and other Western States negotiated a compact that eventually included five Northwestern States plus Alaska and Hawaii. With the seven compact States' total waste volume constituting about 7 percent of the Nation's total in 1980,[5] Washington agreed to serve as the host State for an indefinite period, providing certain assurances were met by the other member States. The Northwest Compact was ratified by the compact States in 1981, submitted to Congress in 1982, and approved by Congress shortly thereafter.

The Northwest Compact set criteria under which it would consider entering into a contract with an unaffiliated State to dispose of its waste. The criteria include that a State cannot be a member of any compact that was ratified as of April 23, 1987; it cannot generate more than a 1,000 cubic feet of LLW annually; and it must be contiguous to a Compact member State.

The operator of the Northwest Compact's disposal site, US Ecology, Inc., explored the profitability of adding a mixed LLW disposal facility to the Hanford, WA site, to receive the Compact's mixed LLW and out-of-region mixed LLW. However, with Washington's policy to accept no out-of-region LLW, including mixed LLW, after 1992, US Ecology, Inc. found that the Compact would generate insufficient volumes of mixed LLW to justify the development and operating costs. The Compact is currently studying other options for managing its mixed LLW. It has conducted two regional surveys of potential mixed LLW generators to determine the volumes of mixed LLW generated and stored and to determine waste minimization and treatment practices used by the generators.

As of November 1989, the Compact had made no provisions for mixed LLW disposal. Since the milestones in the LLRWPAA are for States that do not have access to a site, Governors' certifications from the Northwest Compact States will not be required. The State is working on the national mixed LLW problem, to understand and resolve the problems that are hindering States from managing their mixed LLW.

Recognizing that at some point its LLW disposal site will be closed and to ensure that the necessary funds are available for its closure, the State of Washington commissioned a two-phase study to develop design specifications and cost estimates for closure. The State has studied financial assurance requirements for liability and cleanup associated with LLW management activities. The State is also attempting to ascertain the volumes, types, and curie content of the LLW disposed of at the site, which has been operated since 1965.

Rocky Mountain Compact

Member States: New Mexico, Wyoming, Colorado, Nevada

Current Host State: Nevada

Future Host State: Colorado

The State of Nevada used to some degree the Western Interstate Energy Board, as did Washington, to assist in the negotiation of a compact. Prior to passage of the LLRWPAA, Nevada had taken about 8 percent of the Nation's total LLW—the smallest percentage of the three sited States. Nevada was interested in taking an even smaller amount of waste and, therefore, selected as compact partners several of the lowest volume producers in the country. While Nevada agreed to continue to serve as the host State temporarily, the compact did include a mechanism for selecting a successor host State. Nevada required that only States that generate more than 20 percent of the compact's waste would be required at some point to serve as the region's host State. Arizona, Colorado, Wyoming, Utah, and New Mexico were all originally eligible to join the Compact.

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[5] This 7 percent volume does not represent the total waste volume from the *Nation* being accepted at the Richland site in 1980; the site was accepting about 12 percent of the Nation's LLW.

Arizona decided not to join the Rocky Mountain Compact. Arizona had several large nuclear power plants scheduled to come online in the late 1980s; therefore, it would be generating large volumes of LLW and would doubtless have been designated as one of the region's successor host States. Colorado, as the largest producer of commercial LLW among the member States, was selected as the next host State. Nevada intends to close the Beatty site at the end of 1992, when Colorado will take over as host State for the Compact.

During the transition period through 1992, the Rocky Mountain Compact has agreed to take waste from small unaffiliated States. In 1987, the Compact signed contracts with Rhode Island and the District of Columbia to accept their waste through 1989. In August 1989, the Compact Board approved the renewal of its contracts with Rhode Island and the District and approved new contracts with Vermont, New Hampshire, Maine, and Puerto Rico to accept their LLW through 1992.

The future host State, Colorado, has adopted siting legislation, and the State Geologic Survey has completed an initial study of the entire State which indicates that six areas of the State appear suitable for further investigation.

In 1988 the Umetco Corp., a subsidiary of Union Carbide, announced its proposal to develop a disposal site near Uravan, CO, for the radium waste from the cleanup of Superfund sites in Denver. At the same time, Umetco also submitted a conceptual design for a LLW disposal facility to be co-located with the radium waste disposal site. The LLW site would accept Class A, B, and C LLW for disposal in mined tunnel cavities in a shale formation. Umetco proposed to license these facilities in two phases; first it would seek a license for the radium disposal in an above-grade disposal facility, and second it would pursue a license amendment to develop the mined cavity disposal site for Class A, B, and C LLW. The second phase would only occur if the company determined that sufficient quantities of LLW were generated in the region to make the operation economically feasible.

Since receiving this proposal, the State of Colorado has issued a license for the radium waste facility. However, because the Rocky Mountain Compact legislation defines LLW to include radium waste, any site licensed to accept radium waste generated in the Compact must also be designated as a regional LLW facility by the Compact Board. The Colorado Department of Health petitioned the Compact Board to designate the Umetco site as a regional facility and on May 8, 1989, the Compact Board approved Colorado's petition. However, the facility will likely not be constructed because the Environmental Protection Agency (EPA), which is responsible for deciding where to dispose of the radium waste from the Denver Superfund sites, has contracted to ship it to a site in Utah.

Other private companies have been interested in developing a LLW disposal facility in Colorado, but no formal proposals have been made as of November 1989. The State and Compact are reviewing other options for providing disposal capacity for the region's LLW after the Nevada site closes at the end of 1992, but no decisions have been made. Both Colorado and the Compact Board are concerned that the region does not generate enough commercial LLW to justify development of a new LLW disposal facility.

As of November 1989, the Compact had made no provisions for mixed LLW disposal. Since the milestones in the LLRWPAA are for States without access to a site, Governor certifications from the Rocky Mountain Compact States will not be required.

If a LLW facility is developed in Colorado, the site operator will pay the host county or municipality a 2 percent gross receipt tax. Since the State government would own the property, the licensee would not be paying any property taxes. The gross receipt tax would be in lieu of such property taxes. One percent of the gross receipts are to be paid to the State's General Fund.

Southeast Compact

Member States: Alabama, Florida, Georgia, Mississippi, Tennessee, Virginia, South Carolina, North Carolina

Current Host State—South Carolina

Future Host State—North Carolina

In 1980, South Carolina received 80 percent of the Nation's commercial LLW. Intent on reducing both the amount of waste accepted and the time during which the State would have to continue serving as a host State, South Carolina initiated compact negotiations with other Southeastern States. Prior to these discussions, South Carolina announced that it was reducing by 50 percent the volume of waste it would accept annually at the site in Barnwell. Furthermore, it announced that it would close the site at Barnwell on December 31, 1992. Provisions to select a successor host State were, therefore, included in compact negotiations. Host State selection was based on criteria such as the volume and radioactivity of commercial LLW generated over a set number of past years, projected future waste volumes, and transportation distances. After lengthy negotiations, in September 1986 the Southeast Compact Commission chose North Carolina as the successor host State.

North Carolina's designation has been hotly debated in the State's General Assembly as anti-compact groups have lobbied heavily for North Carolina to withdraw from the Compact. Numerous bills have been introduced which, if passed, would require North Carolina to withdraw from the Compact and develop a LLW disposal facility only for North Carolina's LLW.

To help persuade North Carolina to remain within the Compact and to host the disposal facility, the Compact amended its legislation to limit the term of the host State to 20 years or 32 million cubic feet of LLW received for disposal, whichever comes first, and restrict to 30 days the ability of party States to withdraw from the Compact after commencement of disposal operations. As a condition for remaining in the Compact, this legislation requires that the party States adopt these amendments as part of their Compact legislation by 1990 and requires congressional approval of these amendments to the Compact by 1992. The legislatures of each member State have adopted the required changes, and congressional action is expected on the amendments during 1989.

North Carolina agreed to remain in the Compact and passed legislation establishing the North Carolina LLW Management Authority and a process for siting a LLW disposal facility for the Southeast Compact. The Authority is responsible for site selection and facility development, operation, and closure. It has selected a facility developer/operator—Chem-Nuclear Systems, Inc.—to design, operate, and close the facility. North Carolina has passed legislation prohibiting shallow-land burial as a disposal design (see ch. 6 for a description of shallow-land burial). Furthermore, the design must use engineered barriers, and the bottom of the waste disposal facility must be no less than 7 feet above the seasonal high water table.

While Chem-Nuclear Systems, Inc. will be responsible for site characterization, the Authority will select candidate sites and the preferred site on which the developer will base the license application. As of June 1989, the Authority had conducted two phases of its preliminary site screening work with the assistance of a private contractor and had eliminated all but 9.5 percent of the State's land area as potentially suitable. The Authority plans to name at least two candidate sites for characterization by late 1989. A final site is to be selected in November 1990. The target date for facility operation is January 1, 1993.

As of November 1989, the Compact had made no provisions for mixed LLW disposal. Since the milestones in the LLRWPAA are for States without access to a disposal site, Governor certifications from the Southeast Compact States will not be required.

The North Carolina Radiation Protection Commission adopted regulations for LLW disposal in 1987 with considerable input from statewide environmental groups and LLW generators. The regulations will be used by the Division of Radiation Protection in the Department of Environment, Health, and Natural Resources to license and regulate the disposal facility since North Carolina is an Agreement State.

The State siting legislation provides extensive opportunities for public participation and gives potential host communities the option of appointing local review committees to receive grants from the State of up to $50,000 per site, to review the State's siting efforts. Once a final site is selected and a license application submitted, the host community may appoint a local review committee, which is eligible to receive $100,000 from the State to hire independent experts to review the license application. The legislation provides for a 2.5 percent gross receipts tax and for payments in lieu of property taxes, since the land would be owned by the State. The governing body of the host community may also impose a privilege license tax on the facility to cover any costs incurred due to the presence of the facility. Finally, the local government may submit concerns it has to the Governor's Waste Management Board for arbitration.

The Authority has hired a number of public information and public participation staff members and has sponsored over 25 community forums throughout the State. The Authority is also encouraging communities to volunteer for consideration as a host community and has received inquiries from several local governments.

To cover all costs incurred by the State related to the LLW disposal facility, disposal fees will be set and collected by the Authority. Until the disposal facility is operational, however, it is unclear how North Carolina will finance facility development. Monies have been appropriated from the State's General Fund and the Authority has proposed a surcharge of Southeast Compact generators to cover prelicensing expenses. The Compact also granted North Carolina $200,000 in 1988 to offset the Authority's operating expenses.

Compacts Without Access to a Disposal Site

The majority of States that did not become members of one of the three sited State compacts have formed compacts with States in a similar position rather than remain unaffiliated. States without access to a site saw three main advantages to this approach. First, by being in a compact, States have the absolute legal authority to exclude waste from outside of their compact. Second, there are substantial economic advantages with larger disposal sites (see ch. 6 on disposal costs). Third, compacts may rotate among members the role of host State, while going it alone commits a State to hosting a site indefinitely.

Appalachian Compact

Member States: Delaware, Maryland, West Virginia, Pennsylvania

Host State: Pennsylvania

The Commonwealth of Pennsylvania was a long-time participant in negotiations for a Northeast Compact, but the State decided to withdraw because it saw the compact as unwieldy given its size and the number of competing political concerns. Recognizing that it was a major generator of LLW, Pennsylvania decided to host a disposal facility. Initially, Pennsylvania negotiated a compact with bordering States with the provision that any States joining the new compact would have to develop a site at some point if the State generated more than 25 percent of the compact's LLW. Agreeing to this provision, Delaware, Maryland, and West Virginia (all small LLW-generating States) signed on to the Appalachian Compact.

The Appalachian Compact was adopted by Pennsylvania in December 1985 and was adopted shortly thereafter by the other member States. The Compact was submitted to Congress and signed into law on May 19, 1988. Even prior to congressional ratification, Pennsylvania began preparing for site selection and the choice of a suitable technology.

With much input from a Public Advisory Committee, public meetings, and submitted public comments and suggestions, Pennsylvania passed its Low-Level Radioactive Waste Disposal Act in February 1988. This law establishes the process for developing a LLW disposal site and assigns overall program responsibility to the Department of Environmental Resources (DER). These responsibilities include regulatory development; operator selection; oversight of facility development, licensing, regulation, inspection, operation, and closure; and approval of transferring the disposal facility responsibility, on closure, to the Commonwealth Custodial Agency.

To enable DER to license and regulate a LLW disposal site in Pennsylvania, the Commonwealth plans to apply to the Nuclear Regulatory Commission (NRC) for the regulatory authority. The Commonwealth initially plans to apply for limited Agreement State status for regulating only LLW disposal (not treatment or storage) and expects NRC to delegate this authority to DER in the near future, pending final adoption of State LLW disposal regulations. These regulations were proposed in July 1988 and were finalized in April 1989. They conform to NRC's LLW disposal regulations where necessary and include requirements on site selection procedures, siting criteria, facility design criteria, operator licensing, permitting and licensing fees, and financial assurance and liability mandated by the LLW Disposal Act.

The Pennsylvania Low-Level Radioactive Waste Disposal Act also assigns the responsibility for adopting the regulations proposed by the DER to the Pennsylvania Environmental Quality Board (EQB). This adoption is the final step needed for the State to apply for limited Agreement State status. Once this step is completed the EQB must determine whether the three potentially suitable sites meet these siting regulations before a detailed siting study can begin. To help review proposed regulations, operator selection, and other program decisions, the law also establishes a permanent 23-member LLW Advisory Committee comprised of citizens, public interest groups, generators, and legislators.

The DER selected an operator-license designee, responsible for site selection; license application preparation; and facility construction, operation, and closure in July 1989. Once a contract has been signed, the site operator will begin screening the State for potentially suitable areas. The DER estimates that three potentially suitable sites will be selected by December 1990 for submission to the EQB. Therefore, the Appalachian Compact member States will have to submit Governors' certifications for their LLW, including their mixed LLW, to meet the LLRWPAA January 1, 1990, milestone. Following the selection of three potential sites, the operator will characterize them and choose one on which to base its application for a LLW disposal facility license. The final site is expected to be selected and a license application to be submitted to DER by mid-1992. After issuance of the license in mid-1994, facility construction will begin. The facility is expected to be online in mid-1995.

All costs for facility development and operation are to be borne by the generators. DER has proposed legislation in Pennsylvania to assess fees on generators in each member State to help offset the costs of Phase 1 of facility development—costs incurred until the license application is submitted.

The Pennsylvania LLW Disposal Act and the LLW Management and Disposal Regulations include several unique requirements that reflect extensive public input and the General Assembly's goal to go beyond the minimum Federal requirements regarding technology selection, financial assurances and liability, and benefits to host communities. Specifically, the statute prohibits the use of shallow-land burial and requires that the facility be above-grade unless other designs provide significant improvements in protecting public health and the environment. The statute establishes a goal for a "zero release capacity" facility, which will be implemented through ALARA (as low as reasonably achievable) considerations and through a regulatory requirement for corrective action to abate the source of radiation in the event that offsite radiation measures exceed natural background levels. The DER has developed regulations and design criteria that provide for enhanced containment and recoverability.

With respect to financial assurances and liability, the Pennsylvania LLW Disposal Act requires the facility operator to maintain insurance coverage or some other financial assurance approved by DER to provide third-party liability coverage for damage claims resulting from facility operations. The minimum amount of liability specified in the law is equal to the capital cost of the facility. There is no limit to the operator's liability if it can be shown that the operator acted in a negligent, willful, reckless, or intentional manner. In all other claims for damages, the operator's cumulative liability is limited to $100 million plus the amount of insurance required by the DER. The operator is also required by statute to collect a disposal surcharge during operation of the facility to contribute to the Regional Facility Protection Fund (specified at $100 million) which will be used to cover any third-party damage claims against the facility. Most significantly on liability, the statute includes the controversial "rebuttable presumption" provision which presumes that the operator is liable and responsible for all damages and radioactive contamination within 3 miles of the facility boundary without proof of fault, negligence, or causation. To rebut the presumption of liability, the operator must prove that: 1) the operator did not contribute to the damage, 2) the radioactive contamination existed prior to any disposal operations, 3) the landowner refused to allow the operator to conduct a pre-operational survey, or 4) the contamination occurred as a result of some cause other than facility operations. American Nuclear Insurers, which insures the three currently operating LLW disposal sites against third-party claims, has expressed reservations about providing insurance coverage under these circumstances.

The law offers benefits and compensation to local host communities. It provides for direct economic incentives to potential host municipalities and counties and benefits for affected municipalities or counties, as well as extensive local involvement and oversight in facility development and operation. When the site developer submits three potentially suitable sites to the EQB, the DER is required to provide up to $100,000 per site to each host municipality and county to evaluate the proposed sites. The DER then presents its findings to the EQB for consideration. On receipt of a license application, DER must provide funds up to $150,000 to the host municipality and county to conduct an independent evaluation of the license application. The statute also provides for the host municipality and county to appoint one representative each to the LLW Advisory Committee created by the law. Other municipalities may also petition the DER to be designated as an affected municipality, or the DER may designate affected municipalities in the absence of a petition.

The law further requires that the operator establish a reasonable disposal surcharge, with the approval of DER, to provide monies for local oversight and control and direct payments to the host municipality, host county, and affected municipalities.

The governing bodies of the host and affected municipalities are granted exclusive power and authority to determine how the funds are to be spent. For example, monies are available to hire two full-time inspectors for both the host municipality and county; these inspectors are given the right of independent access to inspect any and all records and activities at the site and to carry out joint inspections with DER officials. DER must respond immediately to any emergency complaint of the host inspector and within 24 hours to any written complaint. The local inspectors also have the authority to temporarily shut down the facility pending an investigation by DER, which will retain the ultimate authority for requiring the facility to cease operations. Monies are also available to train and to equip first-responders to handle emergencies at the facility or on the transportation routes serving the site. Monies are also available to support affected county emergency planning, training, and central dispatch facilities to handle emergencies at the facility.

Also included in the law is a property purchase program that guarantees property owners, within 2 miles of the facility boundary, the property value established immediately prior to the operator's submission of potentially suitable sites. This property value is guaranteed for a 2-year period starting on the date the facility license is issued and must be paid by the site operator if a landowner decides to sell his or her land. In addition, school district and property taxes for individuals whose primary residence is within 2 miles of the facility will be paid for the duration of the facility's operational life.

In addition to these compensations, the law requires the operator to provide for an independent surface water, plant, and soil sampling program for areas within 3 miles of the site boundary and independent continuous air, well water, surface water, and soil sampling at the facility boundary. Results from these sampling programs must be provided to the host county and municipality, to affected municipalities, landowners, home-owners, and to DER. Furthermore, prior to waste acceptance at the facility, and every 3 years thereafter, the operator must provide health surveys related to cancer and other disease rates and to birth defects for the population within a 5-mile radius of the facility. The operator is also required to offer, free of charge, whole-body radioactivity readings and other tests for the presence of internal radioactive emitters to all permanent residents within the host municipality or within a 5-mile radius of the facility boundary.

Central Interstate Compact

Member States: Arkansas, Kansas, Louisiana, Oklahoma, Nebraska

Host State: Nebraska

The membership of the Central Interstate Compact is composed of States that generally were not included in the membership of other compacts surrounding the region. While several member States of the Central Interstate Compact are affiliated with the Southern States Energy Board, South Carolina was not interested in including them in the Southeastern Compact. Other Central Interstate Compact members were not included in the Midwest Compact or the Rocky Mountain Compact. The Southern States Energy Board did, however, assist the Central Interstate members in negotiating the provisions of their compact.

The Central Interstate Compact was ratified by its five member States in 1982 and submitted to Congress. It was ratified along with six other compacts with the passage of the LLRWPAA in 1985. The Central Interstate Compact was unique among all compacts in the powers that it gave the compact commission and the site developer. As originally envisioned, the compact commission would have reviewed site-specific plans submitted by commercial site developers. In other words, in choosing a site developer, the commission would simultaneously select the host State and the host community. Opposition to this one-step process and a desire for more participation by the public and the member States led to a revision of the original procedures. Under the revised plan, the commission would select a site developer, and the site developer in turn would recommend a host State. After these decisions, the designated host State and the site developer would work together to nominate host sites.

In accordance with this plan, the Central Interstate Compact Commission picked US Ecology, Inc. in June 1987 as the site developer for the region. US Ecology, Inc. recommended Nebraska for the region's host State. The Compact Commission approved this recommendation and named Nebraska as the host State in late 1987. Nebraska Governor Kay Orr established several conditions under which the State would accept this responsibility. These conditions were enacted into law by the State legislature as part of the Nebraska Low-Level Radioactive Waste Disposal Act in April 1988, which was amended in May 1989.

The legislation designates the Nebraska Department of Environmental Control (DEC) as the lead agency for overseeing the siting and licensing of the LLW disposal facility, including the development of siting criteria and disposal facility design requirements. The Radiological Health Division of the Department of Health is also assigned responsibility, as the State's designated Agreement State agency, for regulating the facility in coordination with DEC. The two agencies will jointly monitor and inspect the facility once operational. US Ecology, Inc. is responsible for promoting facility development, including site characterization, site selection, facility design, license application preparation, and facility operation and closure.

Legislation failed to pass that would have required local voter approval of any LLW disposal facility sited in Nebraska. This legislation was an outgrowth of a 1988 statewide ballot initiative for a binding referendum which, if passed, would have required the State to withdraw from the Compact and would have required that any LLW disposal site in Nebraska be approved by voters at both the statewide and local levels. Compact and siting opponents were successful in putting the initiative on the November 1988 ballot. They failed, however, to generate sufficient support to pass the referendum, which was defeated by a 64 to 36 percent margin. During this political activity, US Ecology, Inc. formed a Citizens Advisory Committee to provide input into the development of site selection criteria and the site selection process.

Since the Nebraska LLW Disposal Act directs the site developer/operator to seek sites actively in areas where the community has expressed positive interest in hosting the facility, US Ecology, Inc. began its search by asking for interested communities to volunteer for preliminary site screening. Twenty-one counties and 54 communities responded by passing resolutions asking to be considered in the preliminary siting study. In January 1989, US Ecology, Inc. narrowed down the number of potential sites to three, where detailed characterization studies would be conducted. The three sites are located in Nemaha, Nuckolls, and Boyd counties and were selected based on their technical merits as determined by preliminary site studies of their geology, topography, groundwater, surface water, and other environmental characteristics. US Ecology, Inc. has obtained options to purchase the sites, and field work for their characterization began in April 1989.

Nebraska's most recent timetable for facility development indicates that a license application will be submitted to the DEC in mid-1990. Therefore, the Central Interstate Compact member States will have to submit Governors' certifications for their LLW, including their mixed LLW, to meet the LLRWPAA January 1, 1990, milestone. Once the license application has been submitted, it is expected to take approximately 1 year to review it, with license approval expected by mid-to-late 1991. Construction by US Ecology, Inc. will commence following license approval, and the facility is expected to be operational by the beginning of 1993.

As with Pennsylvania's law, the Nebraska LLW Disposal Act as amended includes several requirements that reflect extensive public input regarding technology selection, financial assurances and liability, and benefits to host communities. Specifically, the law prohibits the use of shallow-land burial (as practiced prior to 1979) as a disposal technology in Nebraska and requires that the disposal cells be built above-grade and that they be designed to meet the State's zero-release objectives. Regulations issued by the DEC require the site developer/operator to submit a design for an above-grade disposal unit that incorporates one or more engineered barrier(s) to isolate the waste from the environment.

US Ecology, Inc. submitted a conceptual disposal design for reinforced below-ground concrete vaults (see ch. 6 for a description of this type of design) in its original proposal. The design was reviewed by all member States and was considered an important factor in selecting a developer/operator. Following the Compact's selection of US Ecology, Inc. and the designation of Nebraska as the host State, workshops were conducted in the State to review US Ecology, Inc.'s conceptual design. Public comments received during the workshops indicated strong preferences for an above-grade facility, concrete engineered barriers, and extensive monitoring requirements to ensure immediate detection of any releases from the disposal unit. These suggestions and others have been incorporated as regulatory requirements and as part of US Ecology, Inc.'s final facility design. Nebraska intends to develop disposal capacity for mixed LLW using a very similar disposal technology design, which key State officials feel will adequately address disposal requirements of the Resource Conservation and Recovery Act (RCRA).

As in other States where shallow-land burial is prohibited by law, public input has been a crucial element in the disposal technology selection process in Nebraska. According to State officials, the effort to address public concerns regarding disposal technology designs has increased public acceptance of the facility's design and reduced public concerns regarding the adequacy of the technology.

Public input resulted in the inclusion of several other technical requirements in the Nebraska LLW Disposal Act. For example, no decommissioning waste may be disposed of at the regional facility without DEC's special approval; Class C LLW must be managed separately and stored or disposed of in a retrievable form, and mixed LLW must be treated to the maximum extent practicable prior to disposal.

With respect to liability, the law requires that the Legislature's Judiciary Committee conduct a study of liability issues related to the disposal of LLW and report its recommendations by November 1, 1989.

In addition to Nebraska's community consent policy and its efforts to solicit public input on disposal facility designs, the State has adopted additional provisions establishing local oversight committees (called monitoring committees), benefits packages, and compensation measures for potential host communities:

- $100,000 per site is provided to fund the activities of local monitoring committees during site characterization, and $100,000 per year is provided for the local monitoring committee in the county selected to host the site.
- Local monitoring committees have access to all monitoring data and have authority to contract with independent technical experts during site characterization and with a qualified inspector (with independent access to the facility) during operations.
- A formula is established for allocating the Community Improvements Fund, monies that are provided by the Compact member States and are used as incentives to compensate potential host municipalities, neighboring municipalities within 6 miles of the proposed site, and the remaining political subdivisions of the counties in which proposed sites are located.
- The developer/operator will collect $2 million annually through waste disposal fee surcharges to fund the Community Improvements Fund during the operational life of the facility.
- The DEC must annually offer to sample and analyze well and surface water and any domestic water supply and to test agricultural products at no cost to landowners adjacent to the facility boundary.
- Property owners within 3 miles of the disposal site are guaranteed compensation for any loss in property values caused by the location of the facility for up to 5 years after the site becomes operational.

While the State legislature is still refining the role of the local monitoring committees and the allocation formula for the benefit packages, both the State and site operator are committed to these innovative programs to increase public acceptance. Another incentive to hosting the disposal site is its impact on the local economy. US Ecology estimates that the local economy could be stimulated by as much as $3 million to $6 million annually.

Central Midwest Compact

Member States: Illinois, Kentucky

Host State: Illinois

The first negotiations for a compact in the Midwest involved a large number of States, with attendance sometimes including representatives from as far away as North Dakota and Maryland. Eventually, a core group of States emerged to pursue final negotiations.

Since there was no operating commercial LLW disposal facility in the Midwest, a major topic of discussion was the criteria for choosing the region's host State. Because Illinois generated most of the region's waste and was centrally located, most observers assumed that Illinois would be selected as the first host State. Influential members of the Illinois Legislature made that assumption and amended the compact to reflect their concerns. They insisted that if other Midwestern States wanted Illinois to remain as a participant in the compact, the other member States should adopt the Illinois version of the compact, especially the provision requiring shared liability among all party States in the event of site-related remediation costs. None of the other Midwestern States, however, would adopt the Illinois amendments.

The result of the impasse between Illinois and the other Midwestern States was the submission to Congress of two compacts—a Central Midwest Compact composed of Illinois and Kentucky and a Midwest Compact consisting of eight other Midwestern States (see following discussion of the "Midwest Compact"). The Central Midwest Compact agreed that Illinois will always serve as its host State as long as Kentucky disposes of less than 10 percent of the total LLW from the compact.

The Illinois LLW Management Act, passed in 1983, designated the Illinois Department of Nuclear Safety (IDNS) as the lead agency for site development in Illinois, with responsibility for site selection, licensing, and regulation of the facility. IDNS began the siting process by requesting counties to indicate their interest and, then, by screening potentially suitable areas in 21 counties for exclusionary and favorability factors. By early 1988, IDNS had announced 60 candidate sites in 17 counties from the original 21. Under Illinois law, IDNS can study any site, but a site cannot be selected without approval of the affected county or municipality.

After results of the initial screening activity were published, all of the 21 counties withdrew from the process. However, outside of the 21 counties screened, the Martinsville City Council, the Wayne County Board, and community leaders in Monmouth (Warren County) requested that IDNS select and study potentially suitable sites within their jurisdictions. Martinsville is located in Clark County, where the County Commissioners voted 4 to 3 against further siting studies by IDNS. However, because some potentially suitable Clark County sites fell within the City of Martinsville's jurisdiction, IDNS was able to select sites in the area based on the City Council's request.

IDNS ultimately identified two sites near Martinsville and two sites in Wayne County for detailed study. One Wayne County site was dropped from consideration because IDNS was unable to reach voluntary agreements with local landowners for access to the site and was unwilling to exercise its statutory authority to enter properties with only written notice. Field work has been completed at one site adjacent to Martinsville and at the remaining site in Wayne County, and the second Martinsville site has been held in reserve. The Director of IDNS plans to select a final site by November 1989, based on the findings from the site studies.

In May 1988, IDNS entered into a contract with Westinghouse Electric Corp. as the facility developer/operator. In early May 1989, however, Westinghouse Electric Corp. expressed concern over the issues of facility financing, operator liability, and facility ownership, and Westinghouse Electric Corp. notified IDNS of its intention to cease work. IDNS subsequently contracted with Chem-Nuclear Systems, Inc. to design, finance, construct, and operate the facility. IDNS expects to receive a license application from Chem-Nuclear Systems, Inc. in time for the January 1, 1990, milestone. To meet this milestone, however, Governors' certifications for mixed LLW will be required from both Illinois and Kentucky. Once the license is issued, Chem-Nuclear Systems, Inc. will be responsible for constructing, operating, and closing the facility. IDNS's current schedule calls for the license to be issued in 1991 with the facility construction to begin shortly thereafter. The facility should be operational well before the January 1, 1993, deadline.

Illinois law prohibits the use of shallow-land burial as a disposal technology for LLW generated in the Central Midwest Compact. In March 1988, IDNS promulgated stringent regulations pertaining to the design, construction, and operation of a LLW disposal facility. Particularly significant among these regulations is a 1 millirem per year exposure limit, which is more stringent than the 25 millirem per year exposure limit established by NRC regulations for LLW disposal. To meet these requirements, Chem-Nuclear Systems, Inc. will build an above-grade concrete vault (see ch. 6 for a description of this design) with the waste packaged in modular concrete containers. The vaults will be equipped with leachate collection systems and extensive monitoring systems to allow for prompt detection of any releases of radioactivity from the individual disposal units. As in Nebraska, this design is also intended to meet RCRA requirements for the disposal of mixed LLW.

To build public support for its siting initiatives, IDNS has invested considerable resources and staff time working with statewide environmental groups, local community leaders, and the media. These efforts have produced positive results. Environmental groups in the State have generally been supportive of IDNS's siting program, since they were involved in developing siting policies and disposal regulations through their participation in the statewide Citizens' Advisory Group on LLW. The Citizens' Advisory Group, which consisted of representatives from a variety of groups interested in LLW, employs facilitators from the Conservation Foundation to build consensus on approaches for siting and regulating a LLW disposal facility.

IDNS has opened field offices in Martinsville and Fairfield in Wayne County to establish a presence in the community and to provide information to interested citizens. IDNS has adopted a strict policy of local purchasing for its contractors and itself and has hired several staff employees from the potential host communities. IDNS has also supplied local libraries with a large number of publications and videotapes on LLW management and has sponsored tours of operating LLW facilities for interested members of the community.

IDNS and the Compact have also provided substantial benefits and compensation packages to the potential host communities. IDNS officials have worked closely with locally appointed citizens' advisory committees in Martinsville and Wayne County to promote public involvement in the siting process. In 1988, IDNS approved grants of $500,000 each to Martinsville and Wayne County to hire consultants to independently review the site characterization work being performed by IDNS's contractors. The compact Commission also provided grants of $100,000 to each community to study the potential socioeconomic impacts associated with a LLW disposal facility. In addition to the grants for local review, Martinsville and Wayne County each received $400,000 in "immediate needs" grants from IDNS to be used at the discretion of the local governing bodies. The grant Martinsville received for the second site under consideration was originally offered to Clark County, which turned it down due to continued vocal opposition from a local group opposed to siting the facility in Clark County.

The community ultimately selected to host the site will receive approximately $800,000 per year in direct economic benefits during construction and, subject to negotiation with IDNS and the facility operator, over $1 million per year from waste disposal surcharges collected during the operating life of the disposal facility. The annual compensation will be adjusted to keep up with inflation.

In addition to the benefit packages, Illinois State law includes several provisions concerning local approval and oversight of the disposal facility operations. In 1988, the LLW Management Act was amended to clarify the procedures by which the IDNS must secure the approval of the host community governing body before selecting a final site. The amendments also give the host community governing body the statutory power to close the facility if the facility accepts any waste except LLW or mixed LLW for disposal. IDNS is working with the communities to negotiate contracts for additional economic benefits, safeguards, and provisions for local oversight with the State. The host community may also hire local inspectors to monitor activities at the disposal facility.

IDNS's LLW program and related site development activities are funded by an assessment on nuclear reactors and nonreactor generators of LLW in Illinois. IDNS anticipates spending over $50 million by the end of 1992 in program and facility development costs. A portion of the assessments is currently being placed in the State's long-term care fund, which is expected to reach $4 million to $5 million before the facility opens.

As a result of IDNS's comprehensive LLW management program and its efforts to promote opportunities for public participation in the siting process, the siting effort has advanced rapidly in the State, with IDNS enjoying good relations with most of the local leaders in the Martinsville community. While efforts to build working relationships in Wayne County have been less successful, the majority of County Commissioners still supports the ongoing siting activities being conducted by IDNS and its contractors. A lawsuit requesting an injunction to halt the siting activities in Wayne County was filed by individual members of a citizens' opposition group in Wayne County but does not appear to have the potential to delay the siting efforts. In late August 1989, the plaintiffs in that case moved to dismiss their action. Local nonbinding referenda in Wayne and Clark counties, held in November 1988, saw voters in both counties opposing the location of a LLW disposal site in their counties, but the voters in the City of Martinsville voted in favor of hosting the LLW disposal facility.

IDNS has used a combination of statutory and regulatory requirements supplemented by an active public involvement program to build a significant measure of public support for siting a LLW disposal facility for the Central Midwest Compact in Illinois. State officials have noted that the up-front benefits packages, grants for local review, and the local veto over final site selection have enabled local leaders in Martinsville and Wayne County to view the siting process in a positive light. In addition, public tours of operating facilities have been an important part of IDNS's program.

Midwest Compact

Member States: Indiana, Iowa, Minnesota, Missouri, Ohio, Wisconsin, Michigan

Host State: Michigan

Based on waste generation volumes and transportation factors developed by the Midwest Compact, Michigan was chosen as the first host State for the Compact in June 1987.

Efforts to establish a LLW disposal facility in Michigan began with the enactment of the Michigan LLW Authority Act in late 1987. The Act created the Michigan LLW Authority and set up requirements for establishing a disposal facility. Unlike most State siting authorities or commissions, the Michigan Authority does not have an appointed membership. Instead, the Authority is headed by a single Commissioner appointed by the Governor with the consent of the State Senate. To implement the provisions of the Act the Commissioner is empowered to hire the necessary staff and contractors.

Under the law, the Authority is responsible for site selection, license application, facility design, construction, operation, and closure. To fulfill these responsibilities, the Authority plans to contract with a site developer/operator who will prepare the license application and operate and close the site. The Department of Public Health (DPH) has also been instructed by the legislature to consider applying to the NRC to obtain limited Agreement State status in order to license and regulate the LLW disposal facility. If DPH does not obtain Agreement State status, the disposal facility will be licensed by NRC.

The Authority has developed exclusionary screening criteria that eliminated over 95 percent of the State from further consideration during the first phase of the siting process. A Public Advisory Committee was appointed to assist the Authority in screening the candidate areas and in identifying three candidate sites on the basis of technical favorability factors. Three candidate areas were chosen on October 4, 1989.

The second phase of the process will concentrate on analyzing these areas and will address technical requirements for siting, as well as aspects of public acceptability. Representatives of the Authority plan to meet with local citizens of the candidate areas to explain the subsequent site screening steps and to discern citizens' concerns. The selection of three candidate sites for characterization is scheduled for January 1990. Therefore, the Midwest Compact member States will have to submit Governors' certifications for their LLW, including their mixed LLW, to meet the LLRWPAA January 1, 1990, milestone. Based on information collected during site characterization and preliminary performance assessments, an Environmental Impact Statement (EIS) will be prepared, which will serve as the basis for selecting a preferred site. If the legislature approves of the preferred site, the Authority or its designated site developer/operator will prepare a license application incorporating the EIS. The application will be submitted to DPH and/or NRC depending on whether or not the State has obtained Agreement State status for regulating LLW.

The activities of the Authority are currently funded by the Compact Commission, which levies an export fee on waste shipped to the three operating disposal sites from the region's nuclear utilities. The Compact Commission approved $3 million in export fees to partially fund the Authority's activities budget for fiscal year 1988 and $3.6 million for fiscal year 1989. In the event that Michigan withdraws from the Compact, the Compact and the utilities have negotiated a guaranty agreement requiring the Michigan utilities to repay export fees collected by the Compact Commission from utilities in other member States. Although the affected parties have agreed to the guaranty agreement, the Michigan Public Service Commission has yet to approve provisions for collecting the money for repayment of the export fees if Michigan withdraws. The terms of the negotiated guaranty agreement require that it be in place before additional export fee funds collected by the Compact are disbursed by the Compact Commission to the Authority. As of September 1989, the Commission had transferred $3 million to the Authority. Future transfers are pending final action by the Michigan Public Service Commission.

Michigan did indeed threaten to withdraw from the Compact. On January 30, 1989, Michigan Governor James Blanchard announced that he planned to introduce legislation to withdraw Michigan unless his fellow compact State Governors agreed to join him in requesting congressional action to reduce the number of LLW sites currently planned and to support amendments to the Midwest Compact to address Michigan's concerns regarding shared liability, financial assurances, and institutional stability. The Governor also announced that he was directing the Michigan LLW Authority to immediately halt the State's siting activities until these issues were resolved.

In response to Governor Blanchard's actions, officials in the sited States of Washington, Nevada, and South Carolina informed the Governor of their intent to immediately deny Michigan's LLW generators access to the currently operating sites on the grounds that suspension of the siting activities put the State and Compact out of compliance with the 1988 milestone. The three sited States said that before denying access to generators in the other Midwest Compact States, they would allow these States additional time to either address Michigan's concerns or to take other action necessary to bring the Compact back into compliance.

In making his announcement, Governor Blanchard argued that Federal policy for managing LLW needed reconsideration because significant reductions in LLW volumes coupled with advances in LLW reduction, treatment, and disposal technologies meant that the 13 sites currently planned for development were no longer needed for safe disposal of LLW. Regarding amendments to the Midwest Compact, the Governor stressed the need to amend the Compact legislation to limit the ability of member States to withdraw from the Compact and to impose substantial penalties for withdrawal. The Governor also called for Compact amendments to ensure that the party States would share equally in any financial responsibilities and/or liabilities associated with the construction, operation, closure, and maintenance of the regional disposal facility.

In response to Governor Blanchard's request, the Governors of the Midwest Compact member States agreed to amend the Compact legislation in areas suggested by Governor Blanchard. The member State Governors also agreed to consider any proposals Michigan might advance aimed at reducing the number of LLW sites currently planned for development around the United States. After receiving the commitment of his fellow Governors, Blanchard agreed to resume the activities of the Michigan LLW Authority. Although this interruption did delay the siting process in Michigan, the Authority is still confident that it can meet its January 1990 target date for identifying three suitable sites for characterization. The Authority is currently reviewing its time line for facility licensing and construction as well as other technical criteria and incentive packages provided for in the legislation. The Authority expects to develop legislative proposals to update these requirements and to amend the Compact legislation.

As is true in many States, Michigan Legislation prohibits the use of shallow-land burial as a disposal technology for LLW and requires that the waste be disposed of in concrete canisters in above-ground or below-ground engineered vaults (see ch. 6 for a description of these designs).

If problems occur at the site, the legislation establishes a Remedial Action Fund of $10 million to be collected during the operating life of the facility and a Long-Term Liability Fund with annual payments of not less than $500,000 to cover third-party liability claims. The legislation requires that $600,000 be deposited annually into the State's Long-Term Care Fund.

To provide benefits to the host State and host community, the legislation requires the Authority to establish a fee system for the disposal site. Revenues from this system are to be sufficient to cover any and all costs associated with the site development, operation, maintenance, institutional control, and other expenses incurred by the Authority. In addition, these revenues are to cover the costs of regulating the facility, the expenses of the Compact Commission, costs incurred by local monitoring committees in reviewing facility siting, construction and operations; and direct, unrestricted economic benefits to the host State of $500,000 annually and to the host community amounting to $800,000. The legislation also provides for collection of disposal fees to finance an International LLW Research and Education Institute in the host community. The Authority has accepted a joint proposal from the University of Michigan and Michigan State University to develop the Institute.

In addition to the disposal fee, the Authority is required to impose a 20 percent surcharge on waste disposal fees to provide additional benefits and compensation to the State and host community. Under the legislation, the host community is to receive, in addition to the direct economic benefits listed above, 35 percent of the surcharge revenues or $400,000 per year, whichever is greater, and the host county is to receive 15 percent of the surcharge revenues or $300,000, whichever is greater. The surcharge will also provide equal benefits to municipalities that share a boundary with the host community. Provisions are also made for compensating the host community and county for any costs associated with the facility's development and operation; since the State will own the property, the licensee will make payments in lieu of property taxes. The Michigan Environmental Response Fund and the Clean Michigan Fund are also to receive 15 percent each of the 20 percent surcharge.

The Midwest Compact gives final authority over funding of these incentives to the Compact Commission. The Commission has objected to the magnitude of incentives provided for in the Michigan statute, and the Commission and the Authority are currently discussing alternatives.

Northeast Compact

Member States: Connecticut, New Jersey

Host States: Connecticut, New Jersey

Soon after passage of the 1980 LLRWPA, States in the Northeast began discussions to create a regional compact. Initially, participants in the discussions represented all States from Maine to Maryland. State representatives envisioned a large-volume compact along the lines of the Southeast Compact. Negotiating a Northeast Compact, however, presented a unique challenge in terms of trying to balance the benefits and obligations of large-volume States versus small-volume States.

Within the Northeast region were three States—New York, Massachusetts, and Pennsylvania—that frequently ranked among the top 10 generating States in the Nation. On the other hand, the region also contained a number of States that generated comparatively low volumes of LLW. Considerable effort was spent trying to arrange an equitable sharing of the waste disposal and management burden among the various parties. Large-volume generating States were concerned that, under any one-vote/one-State arrangement, the small States would control the process by which a regional host State was chosen. Small States for their part worried about joining a compact where they potentially could be selected as a host State and would have to accept volumes of waste annually that were hundreds of times what they would generate in a year.

Some small-volume generating States proposed that the Northeast Compact draft contain a provision restricting the siting of a regional waste facility to States generating more than 20 percent of the region's waste. Despite repeated efforts, however, the majority of participants could not agree on a mutually acceptable resolution.

Although the Northeast Compact text had been negotiated, only four States enacted it—Connecticut, New Jersey, Delaware, and Maryland. Since the Compact did not contain any language exempting small generating States from hosting a disposal facility, the northern New England States of Maine, New Hampshire, Vermont, and Rhode Island did not ratify the Compact. The Northeast Compact was ratified by Congress in 1985, and Delaware and Maryland chose to withdraw from the Compact and join the Appalachian Compact. Subsequently, the two remaining States—Connecticut and New Jersey—

have examined various ways of equitably distributing the responsibility of establishing a regional disposal facility. Because each State generates approximately the same volume and radioactivity of waste and has similar environmental characteristics, there was no easy way to choose the initial host State. The Compact Commission reviewed four management options for LLW:

1. siting a separate disposal facility in each State for all classes of LLW,
2. siting a disposal facility in one State for Class A LLW and a facility in the other State for Class B and C LLW,
3. developing LLW treatment facilities in one State and a disposal facility in the other State for all classes of LLW, and
4. establishing a mixed waste disposal facility in one State and a disposal facility in the other State for all classes of LLW.

In spring 1989, the Northeast Compact Commission chose the first option, requiring both States to develop separate disposal facilities for all classes of LLW, including mixed LLW. In anticipation of this choice, both Connecticut and New Jersey had already named State authorities and siting boards to establish new LLW disposal sites.

Connecticut—Connecticut has adopted disposal facility siting legislation and has designated several State agencies to play a role in the siting process. Legislation directs the Connecticut Hazardous Waste Management Service (CHWMS) to develop a LLW management plan, to characterize the amounts and types of LLW generated in the region, and to select the disposal technology for the facility. The CHWMS is also responsible for selecting a private firm to develop and operate the facility and for selecting candidate sites and one preferred site for licensing. Site selection and licensing will be based on criteria established by State and Federal agencies, including the Connecticut Siting Council and the Connecticut Department of Environmental Protection (DEP). The law requires the Siting Council to issue a certificate of public safety and need and requires DEP to issue permits before a LLW disposal facility can be developed on the site selected by CHWMS. The CHWMS plans to select a facility developer/operator to prepare the certification document and license and permit applications. The Commissioner of Environmental Protection is responsible for adopting regulations for the construction, operation, closure, and long-term care of the facility. The Siting Council is responsible for developing regulations on siting. Because Connecticut does not plan to apply for Agreement State status, NRC will be responsible for licensing and regulating the site.

The CHWMS hopes to issue a request for proposal for a facility developer/operator in April 1990 and hopes to select a final site for characterization by July 1990. Therefore, Connecticut will file a Governor's certification for its LLW waste, including mixed LLW, to meet the LLRWPAA January 1, 1990, milestone. The State's schedule calls for a license application to be submitted by the January 1, 1992, deadline and for the site to be online by April 1994.

Legislation has been adopted that establishes a policy for funding Connecticut's facility development program. The legislation allows the State to assess LLW generators a fee (based on volumes of LLW shipped for disposal) that will produce sufficient revenues to cover the State's facility development costs incurred until construction begins. The legislation also includes reporting requirements for LLW generators and civil penalties for not reporting or for reporting inaccurate information.

Connecticut saw oversight as critical to site development and passed legislation establishing an 11-member Radioactive Waste Advisory Committee to monitor the siting process. The legislation also provides for a local project review committee to represent the host municipality during the facility development process. Furthermore, it directs the facility developer to deposit $100,000 with the Connecticut Siting Council on submission of the application for a certificate of public safety and necessity; the money is to be used by the local project review committee to obtain technical assistance as necessary to review the facility license application. The facility operator is also responsible for providing sufficient funds for the host municipality to hire a full-time inspector; in addition, the operator must pay for annual sampling of drinking water wells within 1 mile of the facility. The DEP is responsible for overseeing the drinking water sampling program. Finally, this legislation grants full access to the facility and to all records to the chief elected official of the host municipality or his or her designee.

Provisions are also made in Connecticut's legislation for incentives and compensation to the host municipality. The law provides for an adjustable gross receipts tax of up to 10 percent on facility revenues to be paid to the host municipality and requires the facility operator to negotiate a compensation package of up to $150,000 to mitigate any socioeconomic impacts associated with the facility. The legislation also requires the facility operator to make payments to the host municipality in lieu of property taxes, since the property would be State-owned. The operator must also guarantee local residents, within 2 miles of the site, the property values of their land as they were assessed prior to site selection. This guarantee lasts 5 years after the site becomes operational.

New Jersey—In December 1987, the New Jersey State Legislature passed its Regional Low-Level Radioactive Waste Disposal Facility Siting Act which established the New Jersey LLW Disposal Facility Siting Board as an independent agency housed in the Department of Environmental Protection. The Board is authorized to administer the LLW siting process, including the selection of a firm to construct, operate, close, and monitor the regional disposal facility. The law also establishes the New Jersey LLW Advisory Committee to advise the Facility Siting Board in its activities. New Jersey law prohibits the use of shallow-land burial as a disposal technology and establishes a standard of strict, joint, and several liability for the facility operator.

Members of the Facility Siting Board and Advisory Committee were appointed by Governor Thomas Kean and confirmed by the State Senate in late 1988. Since that time, the groups have been working to implement their responsibilities under the State siting law and the Compact legislation. The Advisory Committee has drafted siting criteria for review by the Board, and the Board is in the process of hiring staff and has a contractor to provide technical assistance and to develop a public education program. As required by State law, the Department of Environmental Protection has surveyed LLW generators in New Jersey to provide information needed to update the regional management plan. Official dates and time lines have not been established for selecting candidate sites or for other critical elements of facility development. New Jersey will have to file a Governor's certification for its LLW, including mixed LLW, to meet the LLRWPAA January 1, 1990, milestone. Funding for the State's activities is being provided from discretionary funds in the State budget and from general revenue appropriations.

The Regional Low-Level Radioactive Waste Disposal Facility Siting Act provides for compensation to the host municipality. Since the disposal site land will be State-owned, the site operator must make payments to the host municipality in lieu of property taxes. The municipality is also to receive a gross receipts tax of 5 percent to cover costs associated with the facility. The Act also exempts the LLW disposal site host municipality from being considered as a site for a solid waste facility or a major hazardous waste facility. In addition, municipalities that currently host solid waste or hazardous waste facilities are exempted from hosting a regional LLW disposal facility.

Southwestern Compact

Member States: Arizona, California, North Dakota, South Dakota

Host State: California

Policymakers in California concluded that no other State was likely to take California's large volume of waste and that California should plan to build its own site. In 1983, California adopted siting legislation and began the process of establishing a LLW disposal facility.

As siting efforts progressed, other unaffiliated Western States, notably Arizona, looked on with interest. Arizona saw major benefits in a compact with California because California was already committed to building a facility and because Arizona had three nuclear reactors coming online in the next decade. Without access to the California site, Arizona would probably have to build its own facility.

Negotiations between California and Arizona spread over several years. During this time, the California Legislature debated, at length, the features of a compact. Meanwhile, the Arizona Legislature passed several alternate compacts which included either South Dakota or North Dakota or both as members.

In July 1988, the California Legislature passed legislation to create the Southwestern Compact, which offered membership to Arizona, North Dakota, and South Dakota. After some debate about Arizona succeeding California as the region's host State in 30 years, Arizona agreed to succeed as the host and the Arizona Legislature ratified the compact in June 1988. With two States as members, the compact was submitted to the Congress for consent. Congress adopted the Southwestern Compact later in 1988. In early 1989, both South Dakota and North Dakota joined the Compact.

Prior to a resolution on these compact negotiations, the State of California passed legislation in 1983 designating the State Department of Health Services (DHS) as the agency responsible for licensing and overseeing the development of a LLW disposal facility. In 1985, the DHS selected US Ecology, Inc. as its licensee designee to site, construct, operate, and close the State's LLW disposal facility. US Ecology, Inc. began the site selection process by focusing on 18 desert basins identified as technically suitable[6] for the safe disposal of LLW. Then, US Ecology, Inc., with the assistance of a Citizens' Advisory Committee (CAC) managed by the League of Women Voters of California, developed siting criteria to exclude portions of these basins from further consideration and to designate high avoidance areas. Based on the input of the CAC and comments from the general public, the criteria were evaluated for relative importance and were used by US Ecology, Inc. to select candidate areas. Public meetings were held in each of these candidate areas to hear local citizens' views.

In February 1987, US Ecology announced the selection of three candidate sites in the southeastern part of the State. After additional site suitability studies, US Ecology, Inc. selected a site in Ward Valley, 25 miles west of Needles, California, as its preferred site. DHS expects to receive the license application from US Ecology, Inc. in November 1989. The Southwestern Compact member States, therefore, will meet the LLRWPA 1990 milestone but will have to submit Governors' certifications for their mixed LLW since licensing activities for it have been deferred. The facility for the nonmixed radioactive LLW is expected to open in mid-1991.

US Ecology, Inc. has proposed to construct a shallow-land burial facility with certain enhancements required by DHS. Since the preferred site is also in a habitat of the threatened desert tortoise, DHS has organized an ad hoc working group to identify potential impacts and to recommend measures to protect the tortoise population.

Prior to the choice of Ward Valley, local residents near the three candidate sites were in favor of hosting the disposal facility because of its direct and indirect economic benefits (e.g., jobs and associated businesses brought to the area). Neither the State nor US Ecology, Inc. however, offered any special incentive packages to the candidate host communities other than compensation for emergency response needs and equipment. The Ward Valley community and statewide environmental groups have voiced some opposition to the site.

Unaffiliated States

States With Siting Plans: Maine, Massachusetts, New York, Texas

Maine—In June 1985, an Advisory Commission was created to advise the Governor and the legislature on radioactive waste management. Despite the small volume of LLW generated in Maine, legislation was passed in 1986 declaring Maine's intent to develop a LLW disposal facility if other means to satisfactorily manage the State's LLW are unavailable. In 1987, the State legislature created the Maine LLW Authority to develop a LLW management plan and siting process for developing a LLW disposal facility only for Maine's LLW. The Authority is responsible for all aspects of site selection, facility development, and operation. The Advisory Committee commented on technical siting criteria developed by the Department of Environmental Protection.

In March 1989, the Authority hired a consultant to develop a statewide site screening methodology for the collection and analysis of existing geologic and environmental data within the State. State law prohibits shallow-land burial as a disposal technology. The Authority is responsible for evaluating disposal technology designs and for selecting a final design in late 1990. The Authority hopes to select a final site by the end of 1991. The majority of the Authority's activities are funded by an assessment on the State's one nuclear utility, Maine Yankee.

Maine's process for selecting a site is unique—it requires local voter approval of the final site within 60 days of the Authority's site selection decision. State law requires that the governing body of the selected host municipality hold a special election to approve the site. Unless 60 percent of the voters approve the site, the Authority must find another location.

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[6] These basins were identified by US Ecology, Inc.'s consultant—Harding Lawson & Associates —as "hydrologically closed" basins, meaning that all surface drainage within each basin is confined within that basin.

Following local voter approval, the facility must receive a favorable recommendation from the State Board of Environmental Protection (BEP). The BEP is required to hold hearings on the technical feasibility and environmental and socioeconomic impacts of the facility and can either deny permission to develop the facility or make a recommendation to the legislature to approve the facility. If the BEP approves the facility, then the State Legislature must also vote to approve its location. Following legislative approval, the facility must be approved by a majority of State voters in a statewide referendum. The facility would also have to be licensed by the NRC, since Maine is not an Agreement State.

Considering the approvals required by Maine law, the Authority estimates that it will not have a disposal facility online until the end of 1995. Maine will file a Governor's certification for its LLW, including mixed LLW, to meet the January 1, 1990, LLRWPAA milestone. So that the Authority can develop a strategy for managing LLW between 1992 and the time when the Maine facility opens, the legislature amended the LLW Authority Act to provide for interim storage of LLW. Interim storage would ensure the continued operation of utilities, industries, hospitals, and research facilities that generate LLW in the event that these generators are denied access to the three currently operating facilities. Storage would either occur onsite or at an offsite storage facility. According to law, onsite storage would last from 1996-2001. If disposal capacity cannot be found by 1996 and onsite storage is not available for all LLW, by law the Authority may begin to develop a storage facility.

In early 1989, Maine presented a proposal to Texas offering financial incentives in exchange for LLW disposal and compact membership. Authority officials have specified in the January 1989 revisions to Maine's siting plan that if a satisfactory compact arrangement can be made, it will be the preferred option for managing the State's LLW. Any plans for Maine to form a compact must be approved by the legislature and Governor and by a majority of the State's voters in a statewide referendum.

If a disposal site is developed in Maine, the law provides for benefits to the host municipality. Specifically, the law requires the site operator to make payments in lieu of property taxes to the host municipality, since the land would be owned by the State. The law also directs the Authority to develop criteria for determining further compensation to be paid to the host municipality. Also, the Authority is in the process of developing a Community Impact Program to evaluate the various benefit packages that could be offered to potential host communities. The Authority has formed a Citizens' Advisory Group to assist in establishing policy and development of the site selection criteria.

In August 1989, Maine entered into a contract with the Rocky Mountain Compact for the Compact to dispose of Maine's LLW through 1992. Maine has to pay the Compact an additional $50 per cubic foot surcharge for disposing of its LLW during this period. This contract will enable Maine to meet the LLRWPAA January 1, 1990, milestone. However, if Maine generates or plans to generate mixed LLW, it will have to file a Governor's certification to satisfy the January 1, 1990, milestone.

Massachusetts—The Commonwealth of Massachusetts has chosen to manage its own waste and not join a compact. Like Maine, Massachusetts has not rejected the option of joining a compact. Massachusetts enacted the Massachusetts Low-Level Radioactive Waste Management Act in December 1987. The law created the LLW Management Board and assigned it primary responsibility for coordinating the State's LLW program and for developing a LLW management plan, selecting a site, and certifying potential facility operators. The law included an initial appropriation of $600,000 from the State's General Fund to cover start-up costs of the program.

The law assigns responsibility to the Department of Environmental Protection (DEP) for developing siting criteria and disposal regulations and to the Department of Public Health (DPH) for developing licensing procedures and requirements. Massachusetts has passed enabling legislation to allow the State to apply for Agreement State status, in which case the DPH would be responsible for licensing the facility.

The LLW Management Board has hired a contractor to assist in the development of a management plan. The Board has appointed a subcommittee to study funding options for waste management activities. The DEP and DPH are in the process of developing and finalizing siting and licensing regulations. A site development timetable has not been finalized by the LLW Management Board.

There are extensive requirements for public involvement in the siting process. Most significantly, the law requires the establishment of a Community Supervisory Committee (CSC) in communities where the LLW Management Board has identified candidate sites for preliminary site characterization. The CSCs are to assist the LLW Management Board in developing site characterization plans and in interviewing potential operators from a pool of qualified candidates certified by the LLW Management Board. After the LLW Management Board selects a site and it is approved by DEP, the CSC in the host community is responsible for selecting a facility operator and a disposal technology. If CSC fails to select an operator within 90 days of site approval, the LLW Management Board selects the operator by a vote of its members. Regarding disposal technology selection, the DPH is prohibited by law from licensing a shallow-land burial facility.

The law establishes a standard of strict liability for any damages resulting from any activity involving LLW management. During operation, closure, and post-closure, the site operator has primary legal responsibility for site cleanup, stabilization, and restoration. During the institutional control period, the primary legal responsibility for these tasks is transferred to the LLW Management Board.

The law also provides compensation to the host and neighboring communities, such as payments in lieu of property taxes, since the disposal site property will be owned by the State, and a gross receipts tax, both paid by the site operator. Furthermore, the Waste Management Board is to make a direct payment of $100,000 annually to the host community during facility construction. The host community is also to receive $1 per curie and $1 per cubic feet of LLW or $200,000 per year, whichever is greater, for 5 years after issuance of the license. The CSCs are also to receive funds for technical assistance to participate in the review of the siting process.

Massachusetts will have to file a Governor's certification for its LLW, including its mixed LLW, to comply with the LLRWPAA January 1, 1990, milestone.

New York—Although New York has not categorically rejected a compact, the State has yet to join one and intends to move forward with its own plans to build a facility for its own waste. In early 1989, the legislature passed a resolution asking Congress to extend the 1993 date for shutting off acceptance of out-of-region waste at the Nation's three currently operating facilities and to redefine LLW to exclude Class C LLW. Congress has taken no action on this request.

In July 1986, the State adopted comprehensive siting legislation in its Low-Level Radioactive Waste Management Act and has since appointed a siting commission and has begun a number of activities required by the law to establish a disposal facility in New York. The five-member New York State LLW Siting Commission is responsible for selecting a site and a disposal technology for New York's facility. Under the law, the Department of Environmental Conservation (DEC) is required to develop LLW disposal and transportation regulations and to certify the site and disposal technology selected by the Siting Commission. The New York State Energy Research and Development Authority (NYSERDA) is assigned to prepare the facility license application and to construct and operate the State's LLW disposal facility. The DEC will license the disposal facility since New York is an Agreement State. The law also establishes a LLW Advisory Committee and assigns responsibility to the Department of Health to develop public information materials on LLW management and the siting process in New York.

Before the facility is constructed, the State's nuclear utilities will be assessed fees covering the State's up-front costs for facility development. The utilities will receive credits for the up-front payments to be applied toward disposal fees once the facility is operational.

The DEC has promulgated regulations for LLW disposal and transportation requirements and is developing additional regulatory requirements for financial assurances, facility design, construction, operation, safety plans, closure, and post-closure. The transportation regulations require transporters of LLW to obtain a permit for each trailer used to haul LLW into, within, or through New York State, and require that each shipment be accompanied by a State manifest form. The regulations also require each truck hauling LLW to carry insurance in the amount of $5 million for a large truck and $1 million for a small truck.

After applying exclusionary screening criteria, the Siting Commission announced in December 1988 the selection of 10 candidate areas for a LLW disposal facility. These areas were selected based on criteria in the Commission's site selection plan developed with the input of the LLW Advisory Committee and local government officials. In September 1989, the Commission issued a staff report on its evaluation of the candidate areas and identified 5 sites within 2 of the 10 candidate areas for further consideration. At least two sites will be selected for characterization in January 1990, and a final site is expected to be chosen in the latter half of 1991.

The Siting Commission has developed a process for selecting a disposal technology with input from the LLW Advisory Committee. The law prohibits using shallow-land burial and requires that the Commission investigate above-grade and below-grade disposal methods as well as mined cavities. The disposal technology selection process also requires that the Commission consider design features that allow for waste recoverability and retrievability. The Siting Commission, with the assistance of a contractor, plans to develop five conceptual designs in 1989, three of which will be selected and developed in more detail as preliminary designs. To select the appropriate technology for the preferred site, the Siting Commission plans to integrate the three preliminary designs with data from characterizing the four candidate sites. The Siting Commission must then submit this site and the disposal design to the DEC for certification. Finally, NYSERDA will submit a license application to DEC. The schedule for issuance of the license and subsequent facility operation is under review. Since a license application will not be completed by January 1, 1990, New York will have to file a Governor's certification for its LLW, including its mixed LLW to meet this LLRWPAA milestone.

The Siting Commission has conducted public meetings in the 10 candidate areas and is currently reviewing potential local impact assistance and incentive packages. Although the law provides for assistance to the host community, the law does not contain specific requirements but does instruct the Siting Commission to recommend appropriate incentive and compensation measures. The Commission has encountered strong public opposition to its activities at several of the public meetings held in the 10 candidate areas.

Texas—In response to the LLRWPA of 1980, Texas decided to build a facility to dispose of its own waste. The siting legislation which Texas adopted in 1981 indicated that Texas did not intend to pursue a compact with other States at that time. However, the possibility of a compact was not rejected altogether.

In 1987, the Texas Legislature instructed the Texas LLW Authority to prepare background materials on joining a compact. The report was presented to the legislature in 1988, and the House Committee on Environmental Affairs held a hearing in October of the same year. The States of Maine and Vermont testified at that hearing, showing their interest in negotiating a compact with Texas. However, the Committee endorsed the long-established Texas policy of taking care of only its own waste, but suggested that the policy could be reviewed if other States offered significant fiscal incentives to cover the costs of constructing a LLW site. In early 1989, both Maine and Vermont submitted proposals for compacts for Texas' consideration. The Authority has also discussed the possibility of forming a small compact with the Commonwealth of Puerto Rico.

The 1981 legislation established the six-member Texas LLW Disposal Authority. The Authority is responsible for siting, facility design, construction, operation, maintenance, and closure. The legislation directed the Bureau of Radiation Control within the Department of Health to develop regulations and licensing procedures for the facility. As the Agreement State agency, the Bureau of Radiation Control will be responsible for licensing and regulating the facility.

The activities of the Authority and related facility development costs are currently funded by appropriations from the State's General Fund. Once the facility is operational, the law requires the Authority to establish a fee system that will be adequate to recover all facility development costs incurred by the State from facility users. The Authority is also considering issuing revenue bonds to fund construction after a license is granted.

The Authority began the siting process by screening the entire State for potentially suitable areas. In 1985, the legislature amended the Authority's statute to give preference to State-owned land. The amendment focused the Authority's site selection efforts on western Texas, where most suitable State-owned lands are located. A more detailed study of these areas resulted in the identification and evaluation of several potentially suitable sites in Hudspeth County.

The Authority selected two sites for further analysis. In 1987, the Authority planned to name a site near Fort Hancock, Texas, in Hudspeth County as its preferred site for characterization, but El Paso County, which is adjacent to Hudspeth County, obtained a temporary injunction to halt the siting activities. The injunction was later overturned by the El Paso County Court of Appeals. A subsequent request for a writ of error was denied by the Texas Supreme Court in January 1988, thus allowing the Authority to proceed with site characterization. When site characterization is complete in late 1989, the Authority plans to designate the Hudspeth County site as its preferred site. The Authority intends to submit a license application by the LLRWPAA January 1, 1990, milestone for its LLW and to file a Governor's certification for its mixed LLW. If construction starts during 1991 as planned, the facility is scheduled to be online by the end of 1992.

Public opposition to the site characterization continues in El Paso County, which has spent over $500,000 to hire geologists and other technical and legal consultants to review the Authority's selection of the Hudspeth County site. One point of El Paso County's lawsuit, regarding the site's proximity to a reservoir, is still outstanding, but the appeals court has ruled that it is inappropriate to consider this issue until site characterization work is complete and the final site named. The Hudspeth County Commissioners have withdrawn from their inter-local government agreement to cooperate with El Paso County in pursuing the lawsuit and intend to use consultants provided by DOE's Nuclear Energy LLW Management Program to independently review the Authority's site characterization work. The consultants for El Paso County have identified several areas of concern regarding the site's geology and proximity to a 100-year floodplain. The Authority is currently discussing these issues with the County's consultants. Further opposition and potential litigation may delay the State's facility development efforts.

With respect to disposal technology selection, the legislation passed in 1987 prohibited shallow-land burial and required containment in concrete or other materials technically superior to unlined trenches. Based on the evaluation of three conceptual designs, the Authority has chosen a preliminary disposal technology design incorporating below-ground concrete canisters and vaults. The Authority has also developed a separate preliminary design for a mixed LLW disposal unit incorporating liner and leachate collection systems necessary to meet RCRA requirements.

The 1987 legislation also approved incentives and a compensation package for the host community. The law authorizes paying the host county 10 percent of the disposal facility revenue, projected at $400,000 to $750,000 annually, for impact assistance. The county may use this money to offset any adverse financial impacts caused by the location of the facility. This compensation and jobs provided by the facility, combined with the Authority's commitment to purchase goods and services locally whenever possible, are intended to provide economic benefits to the host county. The Authority has opened a field office in Fort Hancock where it offers numerous community services and public information programs. The Authority also plans to establish a local advisory committee to study the impacts of the disposal facility, to oversee the distribution of impact assistance funds, and to independently monitor the site.

States and Territories Without Siting Plans: District of Columbia, New Hampshire, Puerto Rico, Rhode Island, Vermont

None of these States or entities has joined a compact, though all prefer to join an existing compact or to contract with a large-volume-generating State to take their relatively small volumes of waste.

District of Columbia—Under the LLRWPAA of 1985, the District of Columbia is considered a State and is required to meet the milestones established by this law. In 1987 the District of Columbia entered into a contract with the Rocky Mountain Compact. Under this contract, the District, like Rhode Island, has been paying an additional $20 surcharge to the Rocky Mountain Compact regardless of which of the three national disposal sites receives the LLW for disposal. In August 1989, the District of Columbia as well as Maine, New Hampshire, Rhode Island, and Vermont, have a contract with the Rocky Mountain Compact for their waste to be accepted through 1992. Under the terms of this new contract, the District will be assessed an additional $50 per cubic foot on LLW shipped for disposal (a $30 increase from its previous contract).

Because of this recent contract with the Rocky Mountain Compact, the District will be in compliance with the LLRWPAA January 1, 1990, milestone, unless it generates or expects to generate mixed LLW, in which case it will have to submit a "Governor's certification" for this waste. The District will still need to examine, however, its options for post-1992 disposal of its LLW, including its mixed LLW, when it will be under the same constraints faced by the other unaffiliated States not planning to develop disposal facilities. The District is also interested in compact options but has not been a party to any recent negotiations.

New Hampshire—New Hampshire is not currently planning to develop a LLW disposal facility. As alternatives, State officials have sought compact membership or a contract for waste disposal with the Rocky Mountain Compact. Initially, in 1987, the Rocky Mountain Compact Board rejected the New Hampshire bid for access to its disposal site, but in August 1989 the Compact Board approved to contract with New Hampshire to dispose of its waste through 1992. Under this contract, New Hampshire must also pay the additional surcharge of $50 per cubic foot for its LLW disposal.

New Hampshire's LLW generators have in the past been denied access to the Nation's three currently operating disposal facilities because the State did not meet the 1988 milestone which required each unaffiliated State either to submit a siting plan for developing disposal capacity or to have a contract in place with a sited compact or State for LLW disposal. Since the State finalized its contract with the Rocky Mountain Compact before January 1, 1990, New Hampshire will be considered in compliance with both the 1988 and 1990 milestones. However, if New Hampshire generates or expects to generate any mixed LLW, the State will have to submit a Governor's certification for this waste to meet the LLRWPAA January 1, 1990, milestone. Moreover, because the Rocky Mountain Compact's disposal site in Nevada is scheduled to close at the end of 1992, New Hampshire must pursue other options for disposing of its LLW, including its mixed waste, after 1992. State officials are interested in forming a compact with other unaffiliated States or joining an existing compact. No formal negotiations, however, have begun as of November 1989.

Puerto Rico—Puerto Rico is considered a State under the LLRWPAA and is required to meet the milestones. Puerto Rico failed to meet the 1986 and 1988 milestones and has been denied access to the three currently operating sites.

Puerto Rico is a small producer of LLW, which is generated in the Commonwealth primarily by medical and research facilities. Puerto Rican officials have discussed compacting options with Texas and are interested in negotiating a contract with a sited compact to meet the 1990 milestone.

Rhode Island—As mentioned, Rhode Island has a contract with the Rocky Mountain Compact to dispose of its LLW through 1992. Under terms of the new contract, Rhode Island is also assessed an additional $50 per cubic foot on LLW shipped for disposal.

Since the contract with the Rocky Mountain Compact enabled the State to meet the 1990 milestone for nonmixed radioactive waste, its generators still have access to all of the three currently operating LLW disposal facilities. If the State generates or expects to generate mixed LLW, it will have to submit a Governor's certification for this waste to meet the January 1, 1990, milestone.

The State will need to examine its options for post-1992 disposal of LLW, including mixed LLW. Although a few new sites may open by the end of 1992, which may consider a contract, two of the three currently operating commercial sites will be closed and the third is not planning to accept LLW from outside the Northwest Compact after 1992. The State is interested in pursuing compact options and has passed legislation for creating a two-State compact with Massachusetts. Massachusetts, however, has not responded favorably to this proposal.

Vermont—Vermont's generators were denied access to the three currently operating disposal facilities because the State failed to meet the 1988 milestone. The State's largest generators had developed adequate storage capacity, and the remaining generators did not produce enough LLW to require expanded storage capacity. As noted, Vermont, however, is now in compliance with both the 1988 and the 1990 milestone (with respect to nonmixed LLW) because it has contracted with the Rocky Mountain Compact to take its waste through 1992.

Vermont as well will have to pay an additional surcharge of $50 per cubic foot for disposing of its LLW. If the State generates or expects to generate mixed LLW, it will have to submit a Governor's certification for this waste to meet the January 1, 1990, milestone.

During the 1989 session of the Vermont Legislature, the House Natural Resources and Energy Committee considered legislation to create a State LLW siting authority but as of November 1989 had not taken any action. The Governor's Office has also submitted a proposal to Texas, similar to the proposal submitted by Maine, to offer financial incentives in return for compact membership.

SUMMARY

States are using a wide range of approaches to develop new disposal capacity for LLW. As envisioned by Congress, the compacts and host States have used the flexibility provided by the LLRWPA of 1980 and the LLRWPAA of 1985 to create programs that will both meet specific compact and State needs and build public support for host State siting efforts.

In developing LLW siting legislation amid growing public awareness about health and environmental risks, State officials draw from previous experience of siting hazardous and solid waste treatment and disposal facilities. Thus, public input has been sought in LLW siting legislation, especially in the areas of disposal technology requirements and the role of potential host communities in the siting process. Most States have worked closely with advisory committees representing diverse interest groups to promote opportunities for public participation and to build consensus on how to manage LLW safely.

The results of these efforts are clearly demonstrated in 10 future host States that have enacted statutory bans on the use of shallow-land burial as a disposal technology even though the Federal regulations consider shallow-land burial a technically suitable disposal method. Despite the technical feasibility of shallow-land burial, public preference for greater isolation of LLW from the environment through the use of engineered barriers and structures has been overwhelming, especially in areas with humid climates. In an attempt to build public confidence and support, the majority of host States have agreed to this preference and are committed to go beyond minimum Federal standards to address public concerns regarding disposal technology. Some States have even gone so far as to establish design goals for "zero release" facilities.

Another area where the public has played a crucial role in developing State LLW siting programs is in expanded public participation in the siting process and increased local oversight of facility siting and operation. Public involvement has also resulted in larger benefit packages and host community guarantees. Most host State siting legislation includes provisions and resources for local review of facility siting plans and oversight and monitoring of facilities once operational. Some States require local approval of sites selected for LLW disposal, and others have granted authority to local officials to hire inspectors and, if necessary, shut down facilities. State siting programs include provisions for mitigating any adverse financial impacts incurred by local host governments from the facility's location and offer substantial economic benefits and guarantees through various means. The overriding philosophy reflected in State LLW siting legislation is that the users of the facility will bear whatever costs are necessary to develop a safe and publicly acceptable facility.

In several States that have advanced to site selection and characterization, efforts to address public concerns have produced positive results. By acknowledging the need for compensation and incentives to offset real or perceived risks, and by recognizing the need for local involvement and oversight, these State programs have enjoyed considerable public support in potential host communities. Although these programs do not guarantee success in the highly emotional and politically charged arena of waste facility siting, they establish a foundation for understanding the Not-In-My-Backyard syndrome.

Of further concern to most States is developing disposal capacity for their mixed LLW. For the most part, States' progress in this area lags behind their progress in developing disposal capacity for nonmixed LLW. All States that generate or expect to generate mixed LLW and are not members of one of the three sited compacts plan to submit Governors' certifications for this waste to meet the LLRWPAA January 1, 1990, milestone.

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REGULATORY FRAMEWORK FOR LLW

Regulatory Authority for LLW

The Nuclear Regulatory Commission (NRC) is responsible for licensing and regulating nuclear facilities and materials and for conducting research in support of the licensing and regulatory process. Federal statutory authority for NRC to undertake these activities is derived from the Atomic Energy Act of 1954 (AEA), as amended[1]; the Energy Reorganization Act of 1974, as amended[2]; and other Federal laws. NRC's jurisdiction covers a variety of nuclear materials and operations, including the treatment, storage, and disposal of low-level radioactive waste (LLW).

Mixed LLW contains both radioactive and hazardous constituents. For its radioactive constituents, mixed LLW falls under NRC jurisdiction because it is a subset of LLW. For its hazardous constituents, mixed LLW is also subject to Environmental Protection Agency (EPA) regulations governing hazardous waste. The principal Federal hazardous waste law is the Resource Conservation and Recovery Act (RCRA) of 1976.[3]

Administratively, NRC has jurisdiction over 17,000 commercial possessors and users of nuclear materials through a network of 5 regional offices and the Agreement State Program. Under the Agreement State Program, NRC may delegate to a State agency regulatory authority over certain nuclear operations if the State agency's program meets the technical and administrative criteria established by NRC. To date, 29 States have obtained Agreement State status, and most States that contemplate licensing a LLW site have or will acquire Agreement State status. States with Agreement State authority regulate commercial practices involving radioactive materials, including subsequent waste management practices. The exception to this authority is the regulation of operations inside nuclear power plants where NRC maintains exclusive authority for licensing and regulating operations.

NRC's regulations in 10 CFR Part 61 address disposal of commercial LLW. These regulations contain:

- performance objectives for the operation of commercial LLW disposal facilities;
- technical requirements for the siting, design, operation, closure, and post-operational activities of LLW disposal facilities;
- technical requirements for waste stability;
- criteria for waste acceptance;
- criteria for classifying LLW;
- administrative and procedural requirements for licensing disposal facilities;
- administrative requirements for closure, institutional control, and long-term care; and
- provisions for adequate financial assurance.

10 CFR Part 61

"Licensing Requirements for the Land Disposal of Radioactive Waste" were developed during the 5-year period from 1978 through 1982 and were issued in 1983 (10 CFR Part 61). As NRC stated in the summary of its draft Environmental Impact Statement for the regulation, "[c]urrent [pre-1983] NRC regulations for licensing radioactive materials do not contain sufficient technical standards or criteria for the disposal of the licensed materials as waste." The new regulations were developed at the request of a number of affected parties, including the public, Congress, the States, industry, and other Federal agencies, which saw a need for codified regulations tailored for commercial LLW disposal sites.

In developing the new regulations, NRC had the choice of establishing two types of requirements: performance objectives or prescriptive requirements. Performance objectives would establish overall goals for the disposal of LLW and would allow flexibility in how the objectives were to be met. In contrast, prescriptive requirements would specify the details of the design and operation of a LLW disposal facility. Based on analyses that NRC conducted for the Environmental Impact Statement, NRC chose a combination of these two approaches—four general performance objectives supported by technical requirements that are more prescriptive in nature. The four general performance objectives for 10 CFR Part 61 are:

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[1] 68 Stat. 919, 1954.

[2] Public Law 93-438, Oct. 11, 1974.

[3] Public Law 94-580, Oct. 21, 1976.

1. protection for occupationally exposed workers and the public during the operation of the site,
2. protection of the environment over the long-term,
3. protection for any intruder who might inadvertently make contact with the waste material, and
4. assurance that the site will maintain its stability for several hundred years.

NRC regulations in 10 CFR Part 20, promulgated in the early 1980s, already provided protection for workers and the public during operation of a disposal facility. Building on this earlier provision, 10 CFR Part 61 added the important feature, among others, of protecting an intruder who might inadvertently come in contact with LLW.

Protection of Workers During Operation

Operation of the disposal facility must comply with the worker radiation exposure regulations in 10 CFR Part 20. These regulations must be observed for all releases except those governed by 10 CFR Part 61. In addition, every reasonable effort must be made to keep exposures during operation as low as reasonably achievable (ALARA). These regulations are designed to protect workers as well as any member of the public who might be exposed to radiation during operation of the site.

Protection of the General Population From Releases of Radioactivity

Releases from the site into water, air, or soil or through plants or animals must not result in an annual dose to any member of the public of greater than 25 millirems[4] of radiation to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ. As with the operational standards for workers, site operators must take action to assure that any releases of radioactivity to the environment are ALARA.

Protection of Inadvertent Intruders

The design, operation, and closure of the facility must ensure the protection of any individual who inadvertently enters or occupies the LLW site or comes in contact with the waste when institutional control of the waste facility is no longer maintained by the site operator or State. An inadvertent intruder, unaware of the hazards of the disposed waste, might engage in activities such as farming, digging a well, or building a house on the premises. After analyzing situations like these that could result in exposure to the inadvertent intruder, NRC staff established that reasonable protection to intruders must be provided but must still allow disposal of a reasonable volume and variety of LLW. Although a specific exposure limit is not cited in NRC regulations, a working limit of 500 millirems per year to the whole body was assumed in preparing the radionuclide concentration limits and waste classifications in 10 CFR Part 61. This is the annual limit that is currently considered the upper limit for exposure to members of the public.

Assurance That the Site Will Remain Stable

All aspects of establishing and operating a site, from choosing a location to closing the site, are regulated to achieve long-term stability and eliminate the need for continued active maintenance after site closure. This objective reflects lessons learned from failures at now-closed commercial sites and Department of Energy (DOE) facilities. A stable site eliminates or reduces subsidence and water infiltration, thus preventing migration of radionuclides from the site.

Technical Requirements

To achieve the performance objectives described above, NRC developed a number of technical requirements that are more prescriptive in nature for site characterization, facility design and operation, waste form and packaging, and institutional controls.

Site Characterization—Choosing a location for a LLW site begins with eliminating regions with inappropriate characteristics. Siting requirements are based on analyses of closed disposal sites and on recommendations from the U.S. Geological Survey.

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[4] For comparison, humans receive about 360 millirems (or 0.36 rem) a year from natural background radiation (4).

In particular, areas to be avoided are those that are difficult to model, are geologically active, contain exploitable natural resources, and/or have high potential for water intrusion. (See ch. 6 section on "Facility Siting—Natural Site Characteristics" for more detail.)

Facility Design and Operating Practices—NRC requirements for facility design and operation are intended primarily to minimize contact with water. All design features must direct water away from the waste and must minimize contact of water with the waste throughout the waste handling process from storage to closure. Operational and closure features emphasize maintaining the stability of the site by segregating unstable Class A LLW from stable Class B and C LLW and by filling any voids between waste packages. (See ch. 6 for a description of disposal technologies.)

Waste Form and Packaging—The waste classification system (see below) dictates the form and packaging in which LLW can be accepted for disposal, the location of waste within the disposal facility, and the concentration of radionuclides allowed at a given site. NRC's requirements strictly prohibit disposal of liquid LLW or of solid LLW containing more than 1 percent liquid. Explosive, pyrophoric, and reactive wastes are also prohibited from land disposal. (See ch. 5 section on "Waste Stabilization" for more detail.)

Waste Classification—There are three classes of disposable LLW: A, B, and C. Class A waste is the least radioactive of the three types and will decay within 100 years to levels that are not considered by NRC to pose a threat to public health and safety. Class A waste is not required to be stabilized but must be segregated from Class B and C LLW in disposal sites. Class B waste is more highly radioactive and must be disposed of in a form that will remain structurally stable for 300 years. Class C waste is the most highly radioactive of the three classes. Maximum concentrations of radionuclides in Class C LLW are limited to ensure that at the end of 500 years the remaining radioactivity will not pose an unacceptable hazard to an inadvertent intruder or to public health and safety. Class C waste must be stabilized and disposed of either at least 15 feet below the top of the facility or beneath a steel reinforced concrete barrier intended to discourage intrusion for at least 500 years. (See ch. 5 section on "Waste Stabilization" for more detail.)

The waste classification system, through its waste segregation and stabilization requirements, significantly contributes to the long-term integrity of licensed LLW disposal sites.

Institutional Control—Institutional actions are intended to insure the long-term stability of the site and to protect the public. First, the facility must be located on land owned by the State or Federal Government. After the site is closed in accordance with State and Federal regulations, the government owning the site must maintain it and restrict access for up to 100 years. At a minimum, environmental monitoring, periodic surveillance, and minor custodial care must be provided during this period. While the government agency responsible for institutional care may wish to retain a presence for longer than 100 years, after that time the site, through its natural features and design, must be able to meet Federal performance objectives relying only on passive controls such as markers and land records.

Second, financial assurance requirements specify that the site operator supply adequate funds to carry out all activities connected with licensing and provide for appropriate closure and stabilization of the site. The site operator must also ensure that sufficient funds are available to cover maintenance costs and monitoring during the institutional control period.

Summary

NRC performance objectives for the licensing and operation of a LLW disposal site are designed to provide long-term protection of the public and the environment. To a large extent, site operators, States, and other affected parties have some flexibility in how they meet performance objectives. While 10 CFR Part 61 contains numerous technical requirements for the siting, operation, closure, and institutional care of LLW facilities, many of these requirements allow latitude in interpretation and implementation. The regulatory orientation of NRC LLW regulations is clearly aimed at meeting performance objectives rather than at dictating all the minute details of the construction and operation of the site and the treatment and form of the waste.

REGULATORY FRAMEWORK FOR MIXED LLW

Historical Perspective on Mixed LLW Regulation

Waste containing both radioactive and hazardous constituents has been generated since the beginning of the commercial nuclear industry. This waste has come to be known as mixed waste. When the first Federal regulations covering radioactivity were adopted, they were intended to apply to all radioactive materials. Since the amount of commercial waste containing both radioactive and hazardous components has always been small, no special provisions were made by regulators of either nuclear materials or hazardous substances to control this waste stream. Anticipating the need to integrate hazardous waste legislation with existing statutes, the U.S. Congress, in establishing the Resource Conservation and Recovery Act (RCRA) in 1976, added two Atomic Energy Act (AEA) exemptions. Section 1006(a) of RCRA states that:

> Nothing in this chapter shall be construed to apply to (or to authorize any State, interstate, or local authority to regulate) any activity or substance which is subject to the [several Federal laws listed], or the Atomic Energy Act of 1954 except to the extent that such application (or regulation) is not consistent with the requirements of such Acts.

Section 1004(27) of RCRA excludes byproduct, special nuclear, and source material regulated under AEA from the definition of solid waste.

Around 1980, State and Federal agencies began to question generators and site operators regarding mixed LLW. Correspondence between site operators and the Environmental Protection Agency (EPA), which enforces RCRA, raised the question of RCRA applicability to LLW sites and the interpretation of the exclusionary language of Section 1004(27) of RCRA. An August 17, 1983, letter to US Ecology, Inc., the site operator of the Hanford, WA, facility, from EPA Director of the Office of Solid Waste, John Skinner, stated:

> In summary, we have concluded that the wastes and disposal facilities which you discuss are not completely exempt from regulation under RCRA. Therefore, you should be submitting a permit application to the appropriate Regional Office, and your facilities should be complying with the appropriate requirements of the State in which the particular facility is located.

Although no Federal agency took formal action on mixed LLW during the mid-1980s, continuing discussions on the topic among generators, regulators, and site operators brought the issue to congressional and public attention. Since Congress was intent on providing for the management of all types of LLW, an effort was made to address the regulation of mixed LLW as part of the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985.[5]

A number of parties questioned the practicality and feasibility of disposing of mixed LLW in facilities that had to satisfy both NRC and EPA regulations. For this reason, the Senate version of the LLRWPAA contained a section giving lead agency status to NRC in licensing mixed LLW facilities. Key committee and subcommittee chairpersons in the House of Representatives found this proposal unacceptable. They were convinced that the hazardous component of mixed LLW required regulation by EPA or a RCRA-authorized State. The two houses of Congress could not agree on a compromise, so the regulation of mixed LLW was not addressed in the LLRWPAA.

In the following session of Congress in 1986, key committees of Congress held oversight hearings on mixed LLW. The consensus that emerged from these hearings was that mixed LLW should be regulated under the dual jurisdiction of NRC and EPA. Representatives of NRC and EPA were instructed to identify and resolve any regulatory impediments to the management of commercial mixed LLW. The first set of joint guidance which NRC and EPA issued addressed the disposal of mixed waste so that States could use the Federal guidance to meet the first LLRWPAA milestone requiring submission of a siting plan by January 1, 1988. Subsequent to the guidance, States, compacts, and generators have raised additional management issues on mixed LLW that may require the attention of both agencies.

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[5] Public Law 99-240, Jan. 15, 1986.

Before congressional deliberation of the mixed LLW issue, the States that licensed the three operating LLW sites had taken some action on mixed LLW regulation. The facilities at Beatty, NV, and Hanford, WA, never received permission from the State or a Federal agency to accept mixed LLW. Nonetheless, because of uncertainties regarding the interpretation of the AEA exemption to materials containing both hazardous and radioactive materials, any LLW—even that containing some hazardous constituents—was disposed of at these sites. As the issue of dual regulatory jurisdiction received more attention at the State and national level, Washington State, in April 1985, requested that US Ecology, Inc., the operator of the commercial site in Hanford, obtain a RCRA permit to continue receiving mixed LLW. The facility operator chose not to seek the permit and thus mixed LLW disposal was no longer allowed at Hanford. Similarly, as a result of EPA's clarification of RCRA's application to mixed LLW, on July 3, 1986, no mixed LLW disposal has been allowed at the Beatty, NV, facility because the site operator has not obtained the required permit.

South Carolina prohibited the disposal of scintillation vials containing both hazardous and radioactive materials in 1978. This prohibition was due largely to the increase in the volume of these materials that began arriving at the Barnwell, SC, facility after the closing of three other commercial LLW sites in the eastern half of the country in the late 1970s. While some LLW containing hazardous materials may have been disposed of at Barnwell between 1978 and 1987 due to the ambiguity of applying the AEA exemption, South Carolina, on July 6, 1987, expressly prohibited disposal of mixed LLW at the Barnwell site.

As a result of EPA's clarification of the AEA exemption and subsequent State and site operator action, licensed disposal options for mixed LLW have been eliminated. While the ability to dispose of mixed LLW was uncertain in the past and gave rise to legislative and regulatory efforts at the national level to promote additional disposal capacity, at present there are no facilities licensed to accept mixed LLW under both NRC and EPA regulations.

Overview of the Resource Conservation and Recovery Act and Hazardous and Solid Waste Amendments

In 1976, Congress passed RCRA, giving EPA broad authority to develop a comprehensive regulatory program for the management and disposal of hazardous waste. Under RCRA, EPA is responsible for identifying wastes that are subject to regulation and for regulating and permitting generators, transporters, treaters, storers, and disposers of waste covered by the regulations. It also granted EPA broad authority to promulgate regulations as necessary to protect human health and the environment from adverse impacts associated with hazardous waste management. This "cradle-to-grave" regulatory system for hazardous waste was designed to track and regulate waste from the point of generation to the point of disposal.

Congress amended RCRA with the passage of the Hazardous and Solid Waste Amendments Act of 1984 (HSWA)[6] which, among other things, established minimum technology requirements for land disposal facilities and surface impoundments, corrective action requirements for hazardous waste facilities seeking permits under RCRA, statutory deadlines for promulgation of land disposal restrictions and treatment standards, small-quantity generator requirements, and waste minimization requirements. The passage of HSWA shifted the focus away from land disposal of hazardous waste to a more comprehensive management system including waste reduction, recycling, and treatment. Section 1004(5) of RCRA defines hazardous waste as:

- a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may
  - —cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or
  - —pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

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[6] Public Law 98-616, Nov. 9, 1984.

To implement this definition, RCRA required the EPA Administrator to develop and promulgate criteria for identifying characteristics of hazardous waste and for listing wastes to be regulated as hazardous under RCRA. Section 3001(a) of the statute directs EPA to consider the toxicity, persistence, biodegradability, and the potential for bioaccumulation of waste material in developing these criteria, as well as other factors such as flammability, corrosiveness, and other hazardous characteristics.

Under RCRA, hazardous waste is considered a subset of solid waste, which is defined by Section 1004(27) as:

> . . . any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities, but does not include solid or dissolved materials in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under Section 402 of the Federal Water Pollution Control Act, as amended, or source, special nuclear or byproduct material as defined by the Atomic Energy Act of 1954, as amended.

Before a substance can be considered a hazardous waste, it must first be determined to be a solid waste according to the above definition. After determining if a substance is a solid waste and is not a useful product or is being recycled, EPA regulations establish two methods for determining if a material is a hazardous waste and thereby regulated under RCRA. First, EPA lists wastes from specific and nonspecific sources as hazardous waste based on the presence of certain constituents, such as identified carcinogens or mutagens, in the wastes at levels that endanger human health. These are known as "listed" wastes.

Secondly, EPA may determine that a waste material is hazardous because it exhibits one or more hazardous characteristics. EPA considers a waste material to be hazardous if it is ignitable, corrosive, reactive, or toxic. Such a waste is known as a "characteristic" waste. RCRA also considers mixtures of listed hazardous waste or characteristic hazardous waste, which still exhibit hazardous characteristics, as hazardous waste, as well as residue resulting from the treatment of a listed waste.

EPA lists over 400 wastes from various sources as hazardous in 40 CFR Part 261 Subpart D. The criteria for determining if the waste exhibits one or more of the hazardous characteristics mentioned above are included in Subpart C of 40 CFR Part 261. It is the responsibility of the waste generator to determine if the waste material is hazardous based on the conditions outlined above.

Applicability of RCRA to Mixed LLW

After Congress expressed its preference for an administrative solution to the debate on joint regulation of mixed LLW by EPA and NRC, both agencies began working on guidance to assist potential generators and States in developing strategies for managing mixed LLW and establishing mixed LLW disposal capacity. In a July 3, 1986, Federal Register notice[7], EPA required a State to obtain authorization to regulate the hazardous component of mixed LLW under RCRA and formally clarified the applicability of RCRA to waste containing both hazardous and radioactive constituents. This clarification was necessary because of confusion between the interpretation of Section 1004(27) of RCRA, which excludes "source, special nuclear, and byproduct material as defined by the Atomic Energy Act of 1954, as amended...," and the definition of "solid waste" to be covered by the RCRA requirements.

In a subsequent notice of clarification issued in the Federal Register, on September 23, 1988[8], on the application of RCRA to hazardous waste treatment, storage, and disposal facilities (TSDFs) for mixed LLW, EPA stated that RCRA applies to any waste containing both RCRA hazardous constituents and AEA radioactive constituents. This interpretation assumes that if a waste is a mixture of both hazardous and radioactive constituents, only the individual radioactive constituents are exempt from RCRA—not the entire mixture of hazardous and radioactive materials. As a result of these notices, mixed LLW is now formally subject to dual regulation under both RCRA and AEA.

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[7] 51 Federal Register 24504, July 3, 1986.

[8] 53 Federal Register 37045, Sept. 23, 1988.

State Implementation of RCRA

Under RCRA, EPA may delegate to a State agency the authority to implement hazardous waste regulations if the State agency's program is equivalent to the Federal RCRA program. A State program must have the necessary statutory authority and expertise to implement RCRA under State regulations. An authorized State program may adopt requirements that are more stringent and comprehensive than Federal requirements as long as they are not inconsistent with the Federal program. Requirements for a State applying for authorization are listed in 40 CFR Part 271. Although there are some differences, this provision for authorizing a State to assume the regulatory role for hazardous waste is similar in concept to the NRC Agreement State program for regulating radioactive waste.

Before HSWA was passed, a State received RCRA authorization in phases based on the various components of the RCRA regulatory program. A State with full RCRA authorization was considered to have base RCRA program authorization. Following HSWA's passage, EPA assumed responsibility for enforcing the new regulations until the authorized State agency could incorporate them into its regulatory program.

Since HSWA required EPA to promulgate many new regulations, EPA divided the Federal rules required under HSWA authority and pre-HSWA authority into groups—called clusters—based on schedules for when they are to be issued. A State is to incorporate regulatory changes by a cluster deadline and to apply for authorization within a specified timeframe after a cluster of rules is promulgated by EPA. A State with base authorization that fails to adopt the necessary statutory authorities and equivalent regulations in a timely fashion runs the risk of having EPA withdraw the entire RCRA program authorization.

State Authorization for Mixed Waste

Under EPA's approach, the authority to regulate the hazardous component of mixed waste is included in the non-HSWA Cluster III. The July 3, 1986, Federal Register notice required a State with base program authorization to revise its program if necessary and apply for authorization to regulate the hazardous component of mixed waste. The notice allowed a State 1 year from the date of publication to make necessary regulatory changes and to demonstrate that its hazardous waste program applies to all hazardous waste, even if mixed with radioactive waste. A State requiring statutory amendments to regulate the hazardous component of mixed waste is given 2 years from the date of the notice to incorporate necessary changes. A State initially applying for base authorization after July 3, 1987, is required to include authority to regulate mixed waste in its application.

The cluster established deadlines, which extended previous deadlines, requiring States with base programs to demonstrate mixed waste regulatory authority by 1 year—by July 1988, or by July 1989 if a statutory change is required. Furthermore, a 2-month grace period can be granted. The EPA Regional Administrator may also grant States with base authorization a 6-month extension beyond the July 1989 deadline to apply for mixed waste authorization. If necessary, the Regional Administrator may place States on a maximum 1-year schedule of compliance to apply for mixed waste authorization. Given that only nine States have mixed waste authorization as of October 1989, it is likely that most States are or will be placed on the compliance schedule.

Currently, 45 States are authorized for the base RCRA program. Of these States, only Tennessee, South Carolina, Washington, Kentucky, Colorado, Georgia, Utah, Minnesota, and Ohio have received authorization for mixed waste. These nine States are responsible for regulating the generation, treatment, storage, and disposal of mixed waste within their borders. In the remaining 36 States which have base authorization but are not currently authorized to regulate mixed waste, mixed waste is not subject to regulation as a hazardous waste under RCRA and is regulated as a hazardous waste only if the State has adopted specific mixed waste statutes and regulations or is regulating the material under some other State statute or regulation. In the six unauthorized States and territories, EPA administers the RCRA program, including regulation of mixed waste.

Clarification of Interim Status Requirements for Mixed LLW Treatment, Storage, or Disposal Facilities

Under RCRA regulations, hazardous waste TSDFs in existence prior to November 19, 1980—or in existence prior to the effective date of statutory or regulatory changes that bring the facility under RCRA regulation—are eligible for interim status. Interim status allows a TSDF to operate without a final permit under regulations found in 40 CFR Part 265 until EPA or an authorized State makes a formal decision to issue or deny the final TSDF permit. To be eligible for interim status, the owner or operator of a TSDF that meets the "in existence" requirements mentioned above must comply with the notification requirements of Section 3010 of RCRA and must submit a RCRA Part A permit application pursuant to 40 CFR Part 270.70. Without interim status, hazardous waste activities at existing facilities must cease until a final permit is issued, which in some cases might take several years.

On September 23, 1988, EPA issued a Federal Register notice to clarify interim status qualification requirements for TSDFs handling mixed waste. In this notice, EPA determined that TSDFs handling mixed waste in an unauthorized State had to be in existence or under construction as of July 3, 1986, to be eligible for interim status. This "in existence" date differs from the November 19, 1980, date for TSDFs handling only hazardous waste, as it corresponds to the EPA's first official pronouncement that RCRA requirements are applicable to mixed waste.

Owners and operators of TSDFs handling mixed waste that were in existence or under construction by July 3, 1986, and are located in a State which *did not* have base program authorization as of September 23, 1988, were required to submit Part A permit application to the appropriate EPA Regional Office by March 23, 1989.

Owners and operators of TSDFs handling only mixed waste in a State that *did* have base authorization by July 3, 1986, are not subject to RCRA regulation until the State program receives authorization to regulate mixed waste. The latest "in existence" date in a State for determining interim status eligibility is the effective date of the State's mixed waste authorization. However, once authorized, a State may select an earlier "in existence" date on which to base interim status qualifications. For example, a State might choose to select an earlier date to prevent facilities from obtaining interim status because these facilities were not in existence as of the earlier date. As a result, facilities in this situation would have to cease operations until a final permit was obtained and would not be allowed to operate under less stringent interim status requirements. However, as a practical matter, the nine States that have already received mixed waste authorization have not chosen earlier "in existence" dates.

In a State with base authorization, TSDFs handling mixed LLW that have already obtained interim status under RCRA because they handle other RCRA hazardous waste, will be required to submit a revised Part A permit application reflecting their mixed LLW activities within 6 months of the State's receipt of mixed waste authorization.

The owners and operators of the three existing commercial LLW disposal facilities have decided not to apply for RCRA permits to dispose of mixed LLW or for interim status under RCRA. As a result, these facilities are no longer allowed to receive mixed LLW, and mixed LLW generators are presently without available disposal capacity. If these three facilities were to apply for RCRA disposal permits, they would be subject to the HSWA corrective action requirements, which stipulate that the facility owner/operator must address any previous releases of hazardous constituents before a final RCRA permit can be issued.

NRC and EPA Guidance on Mixed LLW

To clarify how dual regulation of mixed LLW is to be implemented, the two agencies jointly developed three guidance documents that address the identification and definition of commercial mixed LLW (8), siting guidelines for mixed LLW disposal facilities (9), and a conceptual design for mixed LLW disposal facilities (10).

The first joint guidance document, issued on January 8, 1987, defines mixed LLW as:

> . . . waste that satisfies the definition of low-level waste in the LLW Policy Amendments Act of 1985 and contains hazardous waste that either (1) is listed

> as a hazardous waste in Subpart D of 40 CFR Part 261 or (2) causes the low-level waste to exhibit any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261. (8)

It was determined that the RCRA exclusion of source, byproduct material, and special nuclear material from the definition of solid waste only applies to the actual radionuclides in the waste. If the radionuclides cannot be separated from the waste, waste containing both radioactive and hazardous constituents falls under dual jurisdiction and must be managed in accordance with the requirements of both RCRA and AEA as implemented by EPA and NRC respectively. This guidance also includes a methodology for generators of commercial LLW to identify mixed LLW.

The second joint guidance document, issued on March 13, 1987, contains combined NRC and EPA siting guidelines for mixed LLW disposal facilities. The guidance states that both NRC and EPA do not consider the absence of EPA's final location standards for hazardous waste facilities (which are currently under development) to be a justification for States and compacts not to proceed with the development of LLW disposal sites, including mixed LLW disposal units in accordance with the LLRWPAA (9). The joint guidance includes a preview of EPA's location standards, combined with NRC's site suitability requirements in 10 CFR Part 61.50. EPA has promulgated **minimum** location standards for hazardous waste TSDFs and has established interim final criteria for identifying areas of vulnerable hydrogeology (6), but EPA has not developed **final** location standards that specify siting criteria for new hazardous waste TSDFs. EPA's schedule for adopting these additional location standards is lagging behind the timeframe needed for States to meet the LLRWPAA. Because of this delay, the agencies combined their existing requirements and guidance and developed 11 siting guidelines for mixed LLW disposal facilities (9) (see ch. 6). The guidance encourages States and compacts planning to develop mixed LLW disposal units in conjunction with LLW sites to stay abreast of EPA's plans for promulgating the location standards required by HSWA.

The third joint guidance was issued on August 3, 1987, and includes a conceptual design for mixed LLW disposal facilities developed by NRC and EPA (10). The agencies consider the conceptual design depicted in the guidance for a mixed LLW disposal unit to be capable of meeting both EPA's minimum technology requirements for liners and leachate collection systems and NRC's requirements for minimizing contact of waste with water. The design is also to assure long-term stability and avoidance of long-term active maintenance, which is required by both agencies. The guidance discusses the need to evaluate mixed LLW disposal technologies on a site-specific basis and the potential for site developers to obtain a variance to EPA's minimum technology requirements.[9] According to the guidance, variations to the conceptual design submitted by license applicants will be reviewed by NRC and EPA on a case-by-case basis to evaluate their acceptability and conformance with Federal regulations. This guidance also discusses facility closure requirements.

EPA and NRC have also discussed the need to develop joint guidance on mixed LLW storage, sampling and testing, inspection and enforcement procedures, and dual licensing and permitting procedures. No final guidance in these areas has been issued by the agencies as of November 1989. In a report for the LLW Forum[10], prepared by Afton Associates, officials from States planning to build mixed LLW disposal facilities voiced the need for guidance in these and other areas to increase the efficiency and feasibility of dual regulation (1). The Forum also saw joint guidance needed on treatment standards for particular mixed LLW, pre-approval of conceptual facility designs, post-closure failure scenarios, monitoring, and remediation.

Dual Regulation of Mixed LLW

There are four potential scenarios for State and Federal regulation of mixed waste under dual jurisdiction:

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[9] To obtain a variance, the site operator must demonstrate that an alternative design and operating practices together with the characteristics of the site location are equally effective in preventing the migration of any hazardous constituent into groundwater or surface water.

[10] The LLW Forum is an association of State and compact officials that was established to facilitate implementation of the Low-Level Radioactive Waste Policy Amendments Act of 1985.

1. regulation by a State radiation protection agency and a State hazardous waste program in an Agreement State that is also an authorized RCRA State,
2. regulation by a State radiation protection agency and by EPA in an Agreement State that is not authorized for RCRA,
3. regulation by NRC and a State hazardous waste program in a non-Agreement State that is an authorized RCRA State, or
4. regulation by NRC and EPA in a non-Agreement State that is not authorized for RCRA.

Generally, NRC and EPA regulations differ in their levels of specificity under their governing statutes. As discussed above, NRC's regulations for LLW disposal are primarily based on performance objectives, allowing the site developer considerable flexibility in meeting them. Conversely, EPA's regulations for managing hazardous waste are prescriptive in many significant areas, such as minimum technology requirements for land disposal, manifest requirements for waste transportation and waste sampling, and verification procedures. Because many of these requirements are also mandated by statute, EPA has little flexibility in developing regulations for their implementation and must incorporate statutory requirements and prohibitions as required by law. Although RCRA does offer some relief from these prescriptive requirements through variances, the statutory standards for demonstrating variances found in Section 3004(d) of RCRA are very stringent.

The provision in RCRA Section 1006(a) for exempting a substance for which RCRA requirements are inconsistent with AEA requirements has been much discussed between EPA, NRC, and States planning to develop mixed LLW disposal facilities. No guidance, however, has been offered by either agency on how to implement this provision. As of November 1989, neither NRC nor EPA has publicly identified any potential inconsistencies under dual regulation that might preclude compliance with either agency's requirements.

Of particular concern to the States planning to build mixed LLW disposal units are the additional procedural and administrative requirements for permitting a mixed LLW facility under RCRA as well as under AEA. To meet the milestones and deadlines prescribed by the LLRWPAA, most States are hoping to integrate RCRA permitting procedures for the mixed LLW disposal unit with the licensing process for their LLW disposal facility. It is unclear whether or not NRC and EPA will issue guidance or rulemaking on dual licensing and permitting because they will only serve as the licensing and permitting authorities for those few States that have not obtained delegated regulatory authority. If such guidance or rulings are not issued, Agreement State programs and RCRA authorized State hazardous waste programs will have little direction in integrating facility approval procedures.

Implications of RCRA Requirements on Mixed LLW Management and Disposal

As of November 1989, NRC and EPA were planning to regulate mixed LLW under their existing hazardous waste and LLW regulations and were not planning to develop regulations specifically for mixed LLW. The two agencies examined the two sets of existing regulations and found that they are consistent with one another—no instances were identified where compliance with one set of regulations would result in noncompliance with the other. However, both agencies recognize the potential for conflicts or inconsistencies to arise when implementing the regulations in site-specific cases.

As mentioned earlier, RCRA Section 1006(a) provides for AEA to take precedence in cases where the application of RCRA regulations are inconsistent with AEA requirements. Neither agency, however, has adopted procedures or regulations for making inconsistency determinations under Section 1006(a). Instead, the agencies plan to review on a case-by-case basis any potential inconsistencies found by generators or site developers. In its September 23, 1988, Federal Register notice, EPA encouraged the regulated community to bring forward actual examples of inconsistencies. If warranted, these examples would be addressed in future rulemakings or guidance.

Since the agencies are not currently planning to develop separate regulations for mixed LLW, the full requirements of the existing regulations will apply. Under RCRA regulations, the generator is responsible for determining if the waste being generated contains a listed hazardous waste or if the waste exhibits any of the four hazardous characteristics of ignitability, corrosivity, reactivity, or toxicity. Generators of mixed LLW containing hazardous constituents are required to notify EPA or the State agency authorized for mixed waste and obtain a generator identification number. Large-quantity generators (those that generate greater than 1,000 kilograms (2,200 pounds) per month) that are planning to store mixed LLW for more than 90 days must apply for a hazardous waste storage permit from EPA or the authorized State agency. Small-quantity generators (those that generate 100 to 1,000 kilograms (220 to 2,200 pounds) per month) may store hazardous waste for up to 180 days without a permit and may store up to 6,000 kilograms (13,200 pounds) for 270 days if the waste must be shipped over 200 miles for management or disposal.

Storing short-lived radioactive waste until the radioactivity decays to below regulatory concern (BRC) levels[11] has been a common LLW management practice. Mixed LLW generators may incur additional costs and regulatory burdens to obtain a RCRA storage permit if they plan to store this waste for the decay of its radioactive materials. Impacts of storage prohibitions related to the Land Disposal Restrictions mandated by HSWA (see the next two sections) may also affect a facility's ability to store mixed LLW.

Generators shipping hazardous waste offsite for storage, treatment, or disposal must complete EPA's Uniform Hazardous Waste Manifest and use a transporter who has an EPA identification number. The waste must be shipped to a permitted or interim status TSDF in accordance with the applicable Department of Transportation (DOT) regulations governing hazardous materials. Mixed LLW generators will have to complete the Uniform Hazardous Waste Manifest, as well as the manifest required by the LLW facility operator. Mixed LLW shipments will also be required to meet DOT regulations for shipment of radioactive materials. In its September 23, 1988, Federal Register notice, EPA determined that NRC's and EPA's packaging and waste transportation regulations are complementary and consistent with DOT regulations. The Federal agencies do not anticipate States or generators encountering any problems with conflicts among Federal regulations. However, in cases where RCRA-authorized States and NRC Agreement States are licensing mixed LLW facilities, the State regulations will apply and conflicts may result where these regulations are more stringent.

After receipt of the hazardous waste at a permitted or interim status TSDF, the waste is managed in accordance with EPA regulations and facility permit conditions. It is the responsibility of the TSDF owner/operator to sample and verify the contents of the waste package. The owner/operator must [illegible] determine that the waste has been properly treated prior to land disposal. This determination may be based on information supplied by the generator [illegible] on the analysis conducted at TSDF.

The sampling of mixed waste containers has been a focus of concern. RCRA requires that samples be taken large enough (100 grams) to be representative, but a large enough sample could result in increased worker exposure to radiation and a violation of ALARA principles. Currently, LLW disposal facilities do not open LLW containers prior to disposal unless external radiation-monitoring indicates the need to further inspect the waste package. EPA and NRC are working on resolving this issue but no final joint guidance has been established as of October 1989.[12]

Currently, many TSDFs that accept hazardous waste have self-imposed prohibitions on accepting radioactive waste, even in *de minimis*[13] quantities. Others cannot accept radioactive waste for treatment, storage, or disposal because they do not have the necessary license from NRC or the appropriate Agreement State agency for managing mixed LLW. At present, there are no commercial TSDFs that have the necessary AEA license and RCRA permit to accept offsite mixed LLW.

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[11] These levels are set by NRC so that BRC waste poses no undue risk to public health and safety and the environment.

[12] EPA and NRC have drafted a document entitled "Characterization Guidance" that addresses the sampling procedure.

[13] *De minimis* waste is different from BRC waste in that *de minimis* waste implies a trivial radiation hazard when disposed of and no regard for cost or technology. BRC waste, in contrast, implies costs will be evaluated against benefits and current technology. This distinction was made by Timothy Johnson in his talk "Below Regulatory Concern Wastes—Identification and Implications for Mixed Waste Management," *Proceedings of U.S. Environmental Protection Agency Mixed Waste Workshop*, Denver, Colorado, July 19-20, 1988, pp. 43-46.

Some mixed LLW generators have developed onsite treatment facilities for mixed LLW, including incinerators operating with AEA licenses and interim status RCRA permits. However, due to the complexities and stringent requirements of obtaining a final RCRA Part B permit, these facilities may opt not to pursue final permits. The development of onsite facilities as an option for treating mixed waste is not considered economically feasible for the majority of generators that produce small quantities of mixed LLW. The Department of Energy has developed treatment capacity for defense mixed waste, including incinerators with RCRA permits. These facilities, however, are not regulated by NRC nor available to commercial generators.

Impact of the HSWA Land Disposal Restrictions

As mentioned earlier, the three existing commercial LLW disposal facilities are not authorized to accept mixed LLW. The Land Disposal Restrictions (LDRs) mandated by HSWA in 1984 will also profoundly affect the future management and disposal of mixed LLW. EPA is promulgating the LDRs as regulations over a $3^1/_2$-year period from November 1986 to May 1990. Once a LDR is effective for a particular hazardous waste, any mixed LLW containing that hazardous component must be treated to an adequate level, as determined by EPA, prior to land disposal in a mixed LLW disposal facility.

As part of HSWA, Congress mandated a schedule for EPA to evaluate all hazardous wastes to determine if continued land disposal of these wastes is sufficiently protective of public health and the environment. If EPA does not meet the statutory deadlines for making specific determinations for certain wastes, these wastes will be prohibited from land disposal. Section 3004(m) of RCRA requires EPA, when issuing its regulations prohibiting the land disposal of particular hazardous wastes, to also promulgate regulations specifying levels or methods of treatment that would substantially diminish the toxicity or reduce the likelihood of migration of the hazardous constituent from the wastes. The goal of these regulations is to minimize short-term and long-term threats to human health and the environment.

Once the treatment standard is met, the statute allows the waste or the residues of waste to be disposed of in a permitted land disposal facility. The legislation allows the EPA Administrator to delay the effective date of the treatment standards and land disposal prohibitions if treatment capacity is not currently available. The Administrator is also responsible for evaluating and granting site-specific petitions requesting land disposal facilities to accept banned waste, based on the finding that there will be no migration of hazardous constituents from the land disposal unit for as long as the waste remains hazardous.

To implement these provisions, EPA has issued or is planning to issue regulations based on the schedule that Congress prescribed in HSWA. (See table 3-1—Schedule for Land Disposal Prohibitions.)

In November 1986, EPA issued LDRs and treatment standards for spent solvents and dioxin-containing waste. On July 8, 1987, the agency issued LDRs and treatment standards for the California List wastes. (See table 3-1 for a list of these wastes.) In August 1988, the agency issued LDRs and treatment standards for the first third of EPA's listed hazardous wastes. The second third of LDRs and treatment standards for EPA's listed hazardous wastes was issued on June 23, 1989. The final third is expected in May 1990.

In establishing treatment standards, EPA identifies wastes with similar physical and chemical characteristics and categorizes them into waste treatability groups. EPA then evaluates technologies to treat these wastes to determine the best demonstrated available technology (BDAT) for each waste treatability group. EPA only considers treatment technologies that have been demonstrated by full-scale operation. Once identified, a technology must meet three criteria; it must:

- be commercially available,
- present less risk to human health and the environment than land disposal of the untreated waste, and
- provide substantial treatment.

Each of these criteria is explained in detail in a November 7, 1986, Federal Register notice.[14] Treatment technologies prohibited under Section 3004(n) of RCRA because of air emissions are excluded as available technologies for purposes of establishing treatment standards.

If EPA concludes that a demonstrated technology does not meet the above criteria and therefore is not available, the treatment standard is based on the next best technology determined to be available. The resulting treatment standards, which are determined to be available, may be expressed as concentration limits based on the performance of the BDAT or as technology-based standards in the regulations. EPA has generally indicated a preference for concentration-based standards. However, if analytic methods for determining concentrations are not readily available, EPA prescribes technology-based standards. To allow the generator considerable flexibility in meeting a concentration-based standard, EPA does not require that the waste be treated using a specific technology.

Possible Variances and Extensions to the Effective Date for Treatment Standards

National Capacity Variance—Due to the lack of available treatment capacity for spent solvents and dioxin-containing waste, EPA granted a 2-year national postponement of the effective date for applying the LDRs and treatment standards, allowing waste containing these materials to be land disposed until the effective date. This reprieve has since passed for these wastes, and the regulations became effective on November 7, 1988.

A similar determination was made for some of the California List wastes. The effective date for LDRs and treatment standards for halogenated organic compounds (HOCs) in total concentrations of greater than or equal to 1,000 milligrams per liter (0.033 ounces per quart) was delayed until July 8, 1989, due to the lack of incineration capacity. In EPA's August 17, 1988, rulemaking, which promulgated LDRs and treatment standards for the first third of the "listed" hazardous waste, EPA issued treatment standards applicable to certain California List HOC waste to allow burning in industrial boilers and furnaces.

Table 3-1—Schedule for Land Disposal Prohibitions

Nov. 8, 1986:	Dioxin-containing wastes (F020, F021, F022, F023, F026, F027, F028) Spent solvents (F001, F002, F003, F004, F005)
July 8, 1987:	California List wastes (liquid hazardous wastes containing: free cyanides, polychlorinated biphenyls (PCBs), and certain metals at or above specified concentration levels, and those liquid hazardous wastes having a pH of less than or equal to 2.0. Also, both liquid and nonliquid hazardous wastes containing halogenated organic compounds at or above specified concentration levels)
Aug. 8, 1988:	At least one-third of all listed hazardous wastes Wastes disposed of in injection wells
Nov. 8, 1988:	Contaminated soil and debris from the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980[a] Section 104 or 106 response actions and RCRA correction actions
June 8, 1989:	At least two-thirds of all listed hazardous wastes
May 8, 1990:	All remaining listed hazardous wastes All characteristic hazardous wastes
Within 6 months of listing or identification (these wastes are not subject to the automatic land disposal prohibition):	Newly listed wastes

[a] Public Law 96-510.

SOURCE: U.S. Environmental Protection Agency, *Land Disposal Restrictions Summary, Volume 1, Solvents and Dioxins*, EPA/530-SW-87-019A, May 1987.

Treatment standards have not been established for California List corrosive wastes, metals, or free cyanides. Generators must, therefore, treat these wastes to levels below the statutory prohibition levels found in RCRA Section 3004(d)(2) or render them nonliquid prior to land disposal. With respect to other California List wastes, the effective date of July 8, 1987, still holds.

The LDRs and treatment standards in effect for dioxins, spent solvents, and the California List wastes are in effect for the hazardous constituent in mixed LLW. However, in issuing the LDRs and treatment standards for the first third of EPA's listed hazardous wastes, EPA decided to postpone the issuance of the first two-thirds of the LDRs and standards for mixed LLWs until it issues the final third in May 1990.

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[14] 51 Federal Register 40572, Nov. 7, 1986.

EPA could decide to grant a national capacity variance for the scheduled listed wastes as well. A maximum 2-year national capacity variance would extend the effective date of these treatment standards to May 1992. However, most of the hazardous constituents known in commercial mixed LLW whose generation cannot be avoided fall into the group of dioxins, solvents, and certain California List wastes, for which treatment standards are in effect now. Nonetheless, if any hazardous constituents in mixed LLW are detected for which treatment standards would not be established until the last third treatment standards are established, a 2-year national capacity variance could extend the effective date of these standards to May 1992.

Case-by-Case Extensions—For the commercial mixed LLWs for which treatment standards are currently effective, generators must either treat the wastes to meet the applicable treatment standards of 40 CFR Part 268.40-43 prior to land disposal or request a case-by-case extension of up to 2 years of the effective date of the treatment standard. To obtain an extension, generators must apply to the EPA Assistant Administrator for a 1-year extension, renewable only once for an additional year. To be considered for an extension, the petitioner must demonstrate that he/she has made a good faith effort to locate an appropriate available treatment facility and that he/she has entered into a binding contract to construct or otherwise provide for alternative treatment or recovery capacity that meets the treatment standard for the entire waste volume. The petitioner must also demonstrate that, due to circumstances beyond his/her control, such alternative capacity cannot reasonably be made available by the applicable effective date.

If an extension to the effective date is granted, the generator may dispose of the restricted waste without treatment. The land disposal unit must either meet RCRA's minimum technology requirements for land disposal facilities or be determined by the Administrator to be equally protective of human health and the environment until the extension expires. To meet the underlying standard for protecting human health and the environment, in cases where LDRs apply but no treatment standard has been established, EPA will require that the generator have the capability to manage the waste for which the extension is requested.

Variances to the Treatment Standard—Under 40 CFR Part 268.44, generators may also apply for a variance from the applicable treatment standard if the particular waste in question is considerably different from the waste used by EPA in setting the treatment standard and if the waste cannot be treated to meet the applicable standard. Although no such variances have been requested for mixed LLW, it is evident that the presence of high levels of radioactivity in certain mixed LLWs could preclude the use of certain hazardous waste treatment technologies necessary to meet applicable standards. For example, such a variance will likely be needed for organic solvents containing high concentrations of carbon-14 and tritium, which if incinerated would escape through an off-gas system.

To obtain a variance, the generator must not only demonstrate that the waste is significantly different, but also that the waste cannot be treated to meet the standard, whether it be a concentration-based or technology-based standard. The generator must also provide an alternative treatment method for the waste, which EPA will evaluate to establish a new treatment standard for the waste if the variance is granted. During consideration of variances to a treatment standard, generators requesting the variance must comply with all applicable restrictions on land disposal. Each application for a variance must include information found in 40 CFR Part 260.20(b)(1-4).

No-Migration Petition—In 40 CFR Part 268.6 of the RCRA regulations, generators of waste restricted from land disposal have the opportunity to petition EPA, through their TSDF permit application, for a no-migration variance. The petitioners must demonstrate that no migration of hazardous constituents from a site-specific land disposal unit will occur for as long as the waste remains hazardous. If the EPA Administrator approves the petition, the waste for which the variance was requested may be disposed of at the specific land disposal facility without treatment. EPA has stated that it "believes there will be very few instances when no-migration demonstrations can be successfully made" (7). EPA identifies likely circumstances where no-migration variances might be used, which include the disposal of relatively immobile hazardous constituents in arid land disposal units with no groundwater recharge and the disposal of small amounts of hazardous waste in stable geologic formations. All variances and extensions must be granted by EPA through rulemaking procedures published in the Federal Register as tentative and final decisions.

Delisting—Generators may also petition the agency to delist the hazardous waste in question to allow disposal in a conventional landfill at any point in the process.

Summary of LDRs and Treatment Standards

The LDRs and treatment standards for spent solvents, dioxin-containing waste, and some California List hazardous wastes are applicable to those mixed LLWs containing these substances as of the effective dates. Surveys of mixed LLW generators indicate that these standards may cover a large portion of total mixed LLWs requiring treatment. With this information in hand, generators of these wastes can begin immediately to meet these standards.

For other hazardous constituents found in mixed LLW, treatment standards will not be established until May 1990. EPA decided to defer establishing treatment standards for listed hazardous wastes until standards for the final third of the scheduled listed wastes are established. This decision was based on the agency's determination that while these hazardous wastes exist in large volumes, only a relatively small volume of mixed LLW containing these constituents is currently being generated. As a result of the deferral, generators of mixed LLW containing hazardous constituents other than dioxins, solvents, or some California List wastes will be allowed to continue storing their waste, despite the storage prohibitions discussed below, until at least May 1990.

Storage Prohibitions Affecting Mixed LLW

As part of the LDRs in HSWA, Congress adopted legislation prohibiting the storage of hazardous constituents restricted from land disposal "... unless such storage is solely for the purpose of accumulation of such quantities of hazardous waste as are necessary to facilitate proper recovery, treatment, or disposal." This prohibition is found in RCRA Section 3004(j) and in 40 CFR Part 268.50. The regulations allow transporters to store manifested shipments of restricted waste for up to 10 days. For TSDFs storing mixed LLW for "the purpose of accumulation. . .," the burden of proof is on EPA or a RCRA-authorized State agency during the first year to demonstrate that the purpose of accumulation does not meet the requirement. Storage of restricted waste beyond 1 year shifts the burden of proof to the TSDF owner/operator to demonstrate that the storage is solely for the purposes outlined in the statute. Since no treatment or disposal facility exists for mixed LLW, it is unlikely that generators would be granted a storage permit. The storage prohibition does not apply to wastes for which extensions or variances have been granted or to wastes that meet applicable treatment standards.

The storage prohibition is a major problem for mixed LLW generators currently storing or planning to store their mixed LLW due to the lack of available treatment and disposal capacity. This prohibition may also make it more difficult for States and compacts planning to submit Governors' certifications to comply with the 1990 milestone of the LLRWPAA of 1985. The sited States, DOE, and NRC have issued guidance and criteria for the 1990 milestone which requires States not in sited compact to document their plans for the post-1992 management of all LLW, including mixed LLW, as part of their Governors' certifications. Many States are contemplating requiring generators to store LLW onsite for an extended period until new LLW and mixed LLW disposal units are licensed and permitted. Most of these new facilities will not be in place until well after 1992.

Storage prohibitions for the majority of untreatable mixed LLWs—those containing dioxin, solvent, or certain California List constituents—are in effect as of November 1988. While case-by-case extensions for treatment could be granted for 1 year and renewed for an additional year, these extensions are unlikely because the generator has to have a binding contract in place for alternative treatment capacity before the extension is granted. A contract will be difficult to arrange given that no commercial facility is operational for treating mixed LLW aside from onsite incinerators and one offsite incinerator that accepts only BRC scintillation fluids.

EPA's ability to allow continued storage of mixed LLW containing restricted hazardous constituents in the absence of treatment and disposal facilities may be limited since the prohibition is a statutory requirement. It may, however, be possible for rulemaking to allow mixed LLW containing restricted constituents to be stored until adequate treatment and disposal facilities are available. Under the current schedule of EPA and NRC issuing guidance on mixed LLW, it is unlikely that such rulemaking will be available before the January 1, 1990, milestone deadline for submission of Governors' certifications. As a result, States may have difficulty complying with the 1990 milestone.

States could go so far as to require generators of mixed LLW containing land disposal restricted constituents to cease their operations. This could potentially cripple utilities, radiopharmaceutical manufacturers, and research and medical institutions.

Generators are currently trying to change their practices so that they do not produce mixed LLW, and, for mixed LLW generation that cannot be avoided, generators are using all available in-house treatment techniques to alter their waste so that it is either solely radioactive or solely hazardous. Nonetheless, some mixed LLW generation cannot be avoided short of shutting down the facilities producing the waste. Generators, in turn, are storing their waste which is illegal if it is a land disposal restricted waste falling into the category of dioxin, solvent, or a California List waste. Generators are pressuring EPA for relief from the storage prohibition. Mixed LLW generators could also begin pressuring the private sector to develop mixed waste treatment facilities. States could also take it upon themselves to develop these facilities, but the result could be that substantial resources and staff would be diverted from their primary responsibility of developing disposal facilities, as required by Federal law.

Regulatory Issues Affecting the Development of Mixed LLW Disposal Capacity

Of primary concern to States and compacts are the additional technical and procedural requirements of dual permitting and licensing of mixed LLW facilities under both RCRA and AEA. Although States with Agreement State status and RCRA programs authorized for mixed waste will actually permit and license these facilities in lieu of EPA and NRC, the two agencies will still be able to exert considerable influence over the process through the development of rulemaking or guidance, imposition of minimum Federal technical and procedural requirements, and issuance of variances.

Although some State officials believe that dual permitting and licensing are workable, these officials also note the additional expense and time required to meet both sets of requirements. One State has estimated that characterizing sites to meet RCRA requirements as well as NRC requirements may increase site characterization costs by $2 million to $4 million per site and could delay the entire facility siting process by up to a year, jeopardizing the State's ability to meet milestones prescribed by Federal law (2). State officials also worry about the dynamic nature of RCRA regulations—the moving target syndrome. They are concerned that the regulations will disrupt the facility development process if additional regulations are promulgated for site selection criteria and disposal facility design in the midst of the process (1).

Regarding disposal facility design requirements, EPA and NRC have promulgated performance objectives and technical requirements which differ in approach. NRC has issued general technical requirements and performance objectives in 10 CFR Part 61, while EPA has prescribed specific engineering features in 40 CFR Part 264. Most significantly, EPA requires that all land disposal units install two or more liners and a leachate collection system above and between the liners to protect human health and the environment. Conversely, NRC calls for the development of free-draining disposal units to avoid the "bathtub effect." NRC's approach depends on trench caps and natural site characteristics to minimize infiltration of water and migration of radionuclides into the environment. (See ch. 6 for a more details on these differences).

While the joint guidance issued by the agencies shows that EPA's minimum technology requirements, which are also statutory requirements, are not likely to preclude compliance with NRC's requirements, the guidance does not address operational concerns resulting from these requirements. One of these concerns is increased worker exposure due to the potential radiological hazard posed by leachate collection and waste verification procedures required by RCRA. States are also interested in how to obtain variances from RCRA minimum technology requirements by demonstrating that their alternative designs provide equivalent protection for human health and the environment. States have requested guidance in both areas (1). Beyond the minimum technology requirements which have given rise to these concerns, other EPA and NRC technical requirements for land disposal units appear to be complementary.

To assist them in licensing mixed LLW facilities, States have requested additional guidance for integrating the administrative licensing procedures of both regulations and have requested that the agencies develop consultative review and preapproval procedures for State conceptual designs for mixed LLW disposal units. Recognizing the tight timetable States are on to develop these disposal facilities, NRC officials informed their Advisory Committee on Nuclear Waste that they plan to assist the States in determining ways to streamline the licensing of mixed LLW disposal units (11). Nonetheless, this effort should be jointly conducted with EPA to ensure that both agencies' regulations are met.

Future Considerations for the Management and Disposal of Mixed LLW

Despite the small volumes of mixed LLW currently generated or projected to be generated, the management and disposal of these materials has been of great concern both to generators who must manage the waste in compliance with two sets of regulations and to State and compact officials who must develop disposal facilities in accordance with both RCRA and AEA requirements. While NRC regulations for treatment of LLW are not as prescriptive as EPA's, EPA regulations will eventually require that all LLW containing hazardous constituents be treated to meet the applicable standard. With no treatment capacity and no assurance of future treatment capacity, generators may not be able to manage these wastes in accordance with EPA's treatment standards. Furthermore, States may not be able to do so after 1992 unless regulations are modified to allow storage while encouraging the development of treatment and disposal capacity. In addition, the radiological impacts on the environment, the public, and workers from mixed LLW treatment will need to be evaluated by the regulatory community.

RCRA regulations are continually evolving which adds to the uncertainty of managing mixed LLW. The small volume of mixed LLW currently being generated, could significantly increase if EPA characterizes waste oil as a hazardous waste.

Another issue that may directly impact mixed LLW management is the development and implementation of a Federal BRC standard and regulations that could theoretically allow mixed LLW with very low levels of radioactivity to be disposed of as a hazardous waste. Currently, NRC has established regulations in 10 CFR Part 20.306 (the Biomedical Rule) for allowing very low concentrations of certain radionuclides in scintillation fluids and animal carcasses to be disposed of without regard to radioactivity. Furthermore, NRC has issued a policy for designating certain waste streams as BRC.[15] NRC staff is also in the process of developing a broad generic policy for exempting certain practices involving radioactive materials from regulatory control. As proposed in the December 12, 1988, Federal Register[16], this generic policy would establish a 10-millirem-per-year individual whole body dose as the limit for BRC determinations. However, EPA plans to propose as part of its LLW standard (40 CFR Part 193) a BRC limit of 4-millirem-per-year effective body dose, the consideration of collective doses, extensive recordkeeping and waste characterization requirements, and the potential for recycling the waste. If EPA's BRC standard is promulgated, NRC's regulations for BRC will have to be modified to conform with the EPA standard. The resolution of this inconsistency between the two agencies' BRC limits may take years. Even once a BRC standard and regulations are in effect, operators of hazardous waste landfills may refuse to accept the BRC mixed LLW. Furthermore, operators of municipal landfills may refuse to accept BRC nonmixed LLW. It is, therefore, unclear what actual impact BRC will have on waste volumes.

In addition, as of October 1989 the Capacity Assurance Requirement imposed by the Superfund

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[15] 51 Federal Register 30839, Aug. 29, 1986.

[16] 51 Federal Register 49886, Dec. 12, 1988.

Amendments Reauthorization Act of 1986[17] directs States to demonstrate that they have the capacity to manage hazardous waste generated within their borders for 20 years. This demonstration is necessary for a State to maintain its eligibility for Federal Superfund money. According to criteria released by EPA, States are also required to address mixed LLW in their capacity assurance submissions to EPA. With no current treatment and disposal facilities, it is unclear how this problem will be solved.

While States have expressed their commitment to providing disposal of mixed LLW, they are not currently able to address storage and treatment uncertainties faced by generators. Unless States and compacts decide to develop mixed LLW treatment facilities (for which they are not directly responsible under Federal or State law), the private sector will have to provide these facilities in a timely fashion to avoid a potential disruption of services provided by mixed LLW generators. Generators are currently studying methods to minimize the amount of mixed LLW generated and treatment options to render the waste nonhazardous, but it seems unlikely that all mixed LLW can be eliminated.

The potential volume reduction of mixed LLW requiring treatment and disposal is a double-edged sword—it may reduce volumes but it may discourage the private development of needed commercial mixed LLW treatment facilities by eliminating economies of scale. To know the types of mixed LLW generated and their volumes nationwide, it may be necessary to conduct a comprehensive survey. A survey could help States in their planning and could provide marketing information to the private sector on treatment facility needs.

In summary, while the requirement that generators and disposal facilities operate under dual regulation may be workable, it presents many challenges and uncertainties. The workability of dual regulation would be enhanced if flexible and practical approaches were taken to ensure that human health and the environment are protected. For example, the EPA could decide to allow generators/operators to store a particular waste for which no treatment capacity and/or no disposal capacity is available. In other words, storage would be allowed if it is not being used in lieu of disposal. This provision would give mixed LLW generators an intermediate option until treatment capacity and disposal capacity are developed and available. EPA could establish this provision to allow intermediate storage when it issues its rule for treatment standards, which will be included in the final third of hazardous wastes (due to be released in May 1990). To ensure that generators do not abuse this provision, EPA could keep authority to rescind the provision if good faith effort is not being made to develop treatment and disposal capacity. An advantage of this approach is that by generators applying for a storage permit, EPA would have a record as to what types and volumes of mixed LLW are being generated. EPA could use the data to better ensure that wastes are not being illegally disposed. The waste treatment industry also could use the data as a marketing tool to develop necessary waste treatment facilities.

NRC and EPA rulemaking and the issuance of additional guidance for mixed LLW would eliminate a number of issues that are impeding the protection of human health and the environment:

- *regulations that are currently unattainable:*
  - —certain treatment standards (particularly for certain problem mixed LLWs (e.g., solvents containing carbon-14 and tritium),
  - —storage prohibitions;
- *regulatory conflicts and inconsistencies:*
  - —waste sampling and testing,
  - —facility inspection and enforcement,
  - —timing conflict between EPA location standards and LLW disposal siting efforts,
  - —timing conflict between States being granted mixed waste authorization and States' schedules to develop LLW disposal facilities;
- *regulatory overlap and duplication:*
  - —procedures for determining inconsistencies between AEA and RCRA,
  - —BRC limits for specific wastes,
  - —facility design variance procedures,
  - —waste package manifest requirements,
  - —licensing and permitting procedures,
  - —recordkeeping,
  - —financial assurance requirements,
  - —facility monitoring requirements,

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[17] Public Law 99-499, Oct. 17, 1986.

—emergency preparedness and prevention requirements,
—post-closure failure scenarios,
—remediation.

The EPA and NRC will have to work closely together in these areas to ensure that States and compacts can meet LLRWPAA milestones and that disposal capacity for both LLW and mixed LLW is made available.

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Chapter 4

Understanding LLW—Its Characteristics, Volumes, and Health Effects

OVERVIEW

Commercial low-level radioactive waste (LLW) in the United States is classified as Class A, Class B, Class C, or Greater-Than-Class C (GTCC), with GTCC waste being the most radioactive. About 97 percent of the total LLW volume is Class A waste. About 3 to 10 percent of all LLW is also considered mixed LLW because it contains low-level radioactive constituents as well as hazardous constituents. Principal generators of commercial LLW and mixed LLW include nuclear power plants, other industries, and academic and medical institutions.

In 1988, about 1.4 million cubic feet of commercial LLW was generated in the United States and disposed of at licensed disposal sites at Barnwell, SC; Richland, WA; and Beatty, NV. This volume of waste would fill about 390 average-size tractor trailers, forming a line over 3$^1/_2$ miles long.[1] This volume contains about 260,000 curies of radioactivity.

Over the last 9 years the volume of commercial LLW shipped for disposal has decreased by about 55 percent. If this trend continues, the volume of LLW shipped for disposal in 1989 should remain at 1988 levels of 1.4 million cubic feet; however, another significant decrease in waste volume will likely occur in 1990 when disposal surcharges are scheduled to double. If available volume reduction techniques are more widely applied and below regulatory concern (BRC) limits are finalized (see ch. 3), LLW volumes will probably continue to decrease over the next several years, perhaps by another 40 to 50 percent (see section on "Implications of Waste Minimization and Treatment Techniques on Future Waste Volumes").[2]

WHAT IS LOW-LEVEL RADIOACTIVE WASTE?

Low-level radioactive waste (LLW) is defined in the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985 by what it is *not*, rather than by what it is. **LLW includes all radioactive waste that is not classified as spent fuel, high-level waste, or uranium mill tailings** (see box 4-A). The majority of LLW volume—Class A waste—contains very low levels of radiation and heat, requires no shielding to protect workers or the general public, and decays in less than 100 years to levels that the Nuclear Regulatory Commission (NRC) finds do not pose an unacceptable risk to public health and safety. The remaining 3 percent of LLW volume—Class B, Class C, and GTCC—requires shielding and can remain harmful for 300 to 500 years or more.[3]

Generators of commercial LLW include: nuclear power plants; fuel fabrication facilities; research reactors; industrial plants using radioactive materials; manufacturers of radioactive instruments and radiopharmaceuticals; hospitals, clinics, and other medical facilities; and other private sector and university laboratories. LLW typically includes an assortment of materials that table 4-1 lists in three general categories of generators.

COMMERCIAL LLW

Each business, institution, or organization that handles radioactive material must be licensed by the NRC or an Agreement State that has been granted licensing authority by the NRC. There are about 17,000 licensees in this country authorized to handle radioactive materials (17). However, each licensee may employ many individuals who work with radioactive material. For example, on nine Univer-

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[1] This analogy using tractor trailers applies to volumes only, not actual transportation scenarios, since tractor trailer weight limits would prohibit the transport of such heavy loads.

[2] Most treatment techniques, versus waste minimization techniques that keep waste from ever being generated, have little effect on reducing the waste's radioactivity.

[3] GTCC waste is the responsibility of the Federal Government to dispose. Isolation of GTCC waste needs to be for a few hundred to a few thousand years. For a thorough discussion of GTCC waste, see U.S. Congress, Office of Technology Assessment, *An Evaluation of Options for Managing Greater-Than-Class C Low-Level Radioactive Waste*, OTA-BP-O-50, October 1988.

Box 4-A—Types of Radioactive Waste

The following types of radioactive waste are differentiated by the nature and intensity of the radiation they emit, as well as by their physical and chemical forms. They are listed roughly in order of decreasing risk to humans.

Spent fuel consists of fuel rods that have been "burned" (irradiated) in commercial, defense, or research nuclear reactors to the point that they no longer contribute efficiently to the nuclear chain reaction. Spent fuel is thermally hot, is highly radioactive, and requires heavy shielding. Commercial spent fuel is being stored at 113 operating commercial nuclear power plants pending the availability of a federally monitored retrievable facility for storage or a deep-geologic repository for disposal.

High-level waste (HLW), as the term is used in this report, is generated when spent fuel is reprocessed to recover plutonium and uranium. The vast majority of HLW in the United States has been generated over the last four decades in support of national defense programs. HLW is highly radioactive, generates some heat, and requires heavy shielding. Most HLW is now stored at Richland, WA; Aiken, SC; and Idaho Falls, ID, pending availability of a deep-geologic repository.

Transuranic waste is generated from the production of plutonium for nuclear weapons, from the manufacturing of sealed radioactive sources, and from the refurbishing or decommissioning of nuclear power plants. Transuranic waste contains radionuclides that have atomic numbers greater than 92, the atomic number of uranium. *Defense* transuranic wastes are currently being stored pending disposal in a deep-geologic repository called the Waste Isolation Pilot Project (WIPP), located near Carlsbad, New Mexico. *Commercial* transuranic waste is included as low-level radioactive waste.

Low-level radioactive waste (LLW) includes radioactive waste not classified as uranium mill tailings, high-level waste, or spent fuel. About 97 percent of all LLW—Class A—has relatively low levels of radioactivity. Class A waste remains hazardous for less than 100 years, Class B and C waste remains hazardous for a few hundred years, while Greater-Than-Class C waste remains hazardous for a few hundred to a few thousand years. GTCC waste is the responsibility of the Federal Government to manage. All classes of commercial LLW can contain transuranic elements.

Uranium mill tailings are the earthen residues—coarse sand and a "slime" of clay-like particles—that remain after extracting uranium from mined uranium ore. These tailings contain low concentrations of radioactive material, but tailing volumes are very large. Mill tailings are found in New Mexico, Wyoming, Colorado, Utah, Texas, Washington, and South Dakota.

Byproduct material is material contaminated or made radioactive during the production or use of special nuclear material.

SOURCE: I.P. Weber and S.D. Wiltshire, *The Nuclear Waste Primer: A Handbook for Citizens*, The League of Women Voters Education Fund (New York, NY: Nick Lyons Books, 1985).

sity of California campuses there are over 15,000 individual users of radioactive material (20).

As shown in figure 4-1, about 1,440,000 cubic feet of commercial LLW (containing about 260,000 curies) was disposed of in 1988 at the three operating commercial disposal sites in Barnwell, SC; Richland, WA; and Beatty, NV. Figure 4-2 indicates that nuclear power plants throughout the country produce over 50 percent of the volume of LLW generated nationwide and over 80 percent of the radioactivity. The LLW from decommissioned nuclear power plants is addressed in appendix B. Industries account for most of the remaining volume and radioactivity. Some of the principal radionuclides found in LLW from different generators are listed in figure 4-2 while their half-lives[4] and type of radiation emitted[5] are listed in table 4-2.

In light of the wide range of materials, their half-lives, and the type of radiation they emit, NRC uses a four-tiered classification system for commercial LLW based on the types and concentrations of different radionuclides in the waste. This classifica-

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[4] Half-life is the time in which half of the atoms of a particular radioactive substance disintegrate to another nuclear form. For example, waste containing 50 curies of a radionuclide with a half-life of 10 years will contain only 25 curies in 10 years. In 10 more years the waste will contain 12.5 curies and this decay process continues. Each radionuclide has a specific half-life. Measured half-lives vary from millionths of a second to billions of years.

[5] Radiation can be emitted as a particle—alpha or beta, or as a ray—a gamma ray or an X-ray. To understand the differences in how these particles and rays affect humans, see the section on "Understanding Radiation and Its Health Effects."

Table 4-1—Principal Generators and Types of Commercial LLW

Nuclear power plants:
Dry solids (e.g., protective clothing, rags, paper, plastics, and other trash); used equipment; sludges, organic solvents, and other liquids; water purification filter media and "resins"; irradiated hardware; and gases.

Industries:
Radiopharmaceuticals; wastes from fabricating nuclear fuel; sealed sources.

Academic & medical institutions:
Dry solids, glassware, plastics, and other laboratory equipment; scintillation fluids and other organic liquids; animal carcasses, medical treatment and research materials; and gaseous wastes.

SOURCE: Adapted from U.S. Department of Energy, *Managing Low-Level Radioactive Wastes: A Proposed Approach*, DOE/LLLW-9, April 1983, p. 206.

Table 4-2—Principal Radionuclides Found in Commercial LLW

Radionuclide	Approximate half-life	Type of radiation emitted
Technetium-99	6 hours	Gamma
Xenon-133	5 days	Beta, gamma
Phosphorus-32	14 days	Beta
Cobalt-58	2 months	X-rays, beta, gamma
Iodine-125	2 months	Gamma
Sulfur-35	3 months	Beta
Magnesium-54	10 months	X-rays, gamma
Cesium-134	2 years	Beta, gamma
Cobalt-60	5 years	Beta, gamma
Tritium	12 years	Beta
Cesium-137	30 years	Beta, gamma
Strontium-90	30 years	Beta
Nickel-61	90 years	Beta
Carbon-14	5,700 years	Beta
Nickel-59	80,000 years	X-rays
Iodine-129	15,700,000 years	Beta
Uranium-235	700,000,000 years	Alpha, gamma
Uranium-238	4,470,000,000 years	Alpha, gamma

SOURCE: Office of Technology Assessment, 1989.

tion system, which NRC describes in 10 CFR Part 61.55, generally reflects the waste's potential long-term hazards to humans.

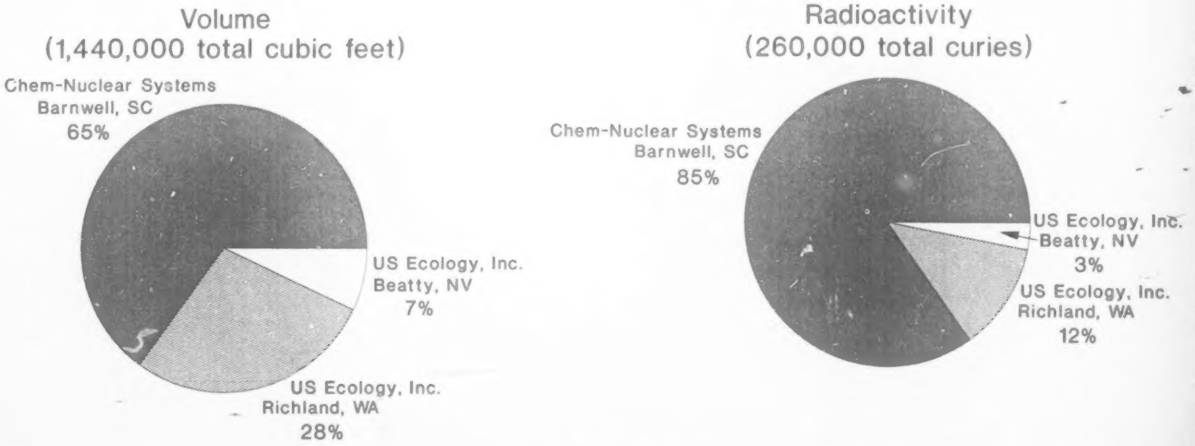
Class A Waste

Class A waste, the least radioactive of the four types, must meet numerous minimum requirements on packaging to facilitate handling of the waste and to protect the health and safety of workers at disposal sites (see ch. 5). Class A waste is normally segregated from other LLW waste at disposal sites, unless the waste meets the more stringent physical stability requirements for Class B and C waste. As indicated in figure 4-3, most of the volume of LLW is Class A waste, although it actually accounts for only a small portion of the radioactivity in LLW.

Class B Waste

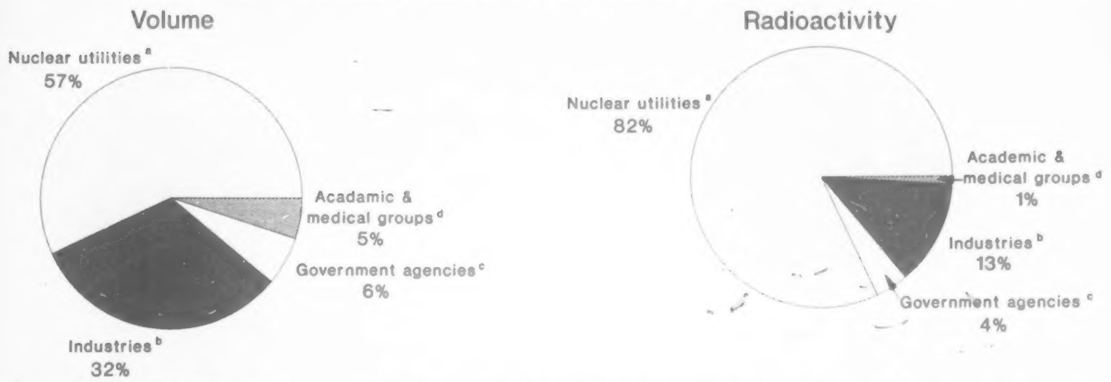
Class B waste has intermediate levels of radioactivity that are generally 10 to 40 times higher than levels for Class A waste. In addition to satisfying all the packaging requirements for Class A waste, Class B waste must be structurally stable for at least 300 years to prevent collapse of the caps that typically

Figure 4-1—Commercial LLW Disposal in 1988



SOURCE: Data provided by EG&G Idaho in May 1989 during the preparation of U.S. Department of Energy, *DRAFT Integrated Data Base for 1989; Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1989.

Figure 4-2—Generators of Commercial LLW Received at Disposal Sites in 1987



Typical radionuclides from different generators:

[a]Nuclear power plants: cobalt-58 and -60, chromium-51, manganese-54, cesium-134 and -137, nickel-59, tritium (i.e., hydrogen-3), zinc-65, and iodine-131.

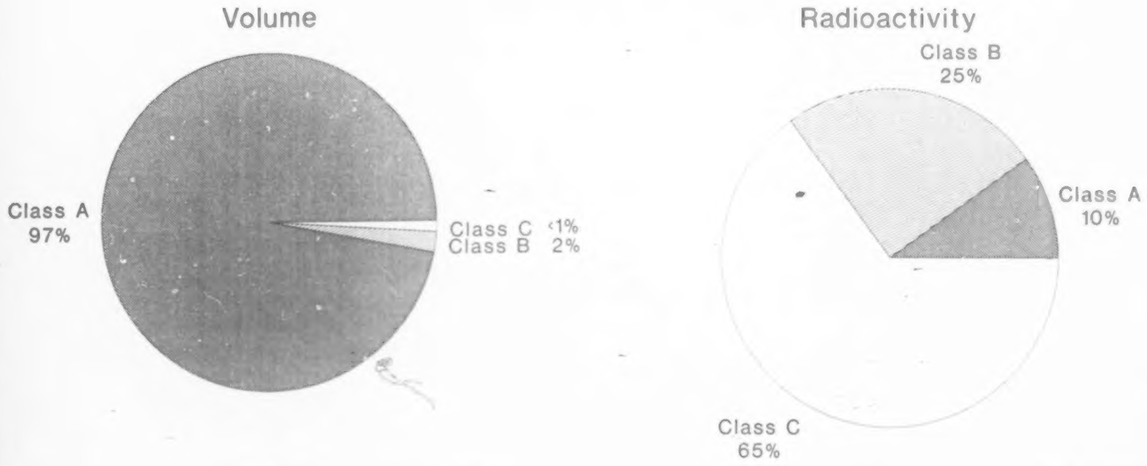
[b]Radiopharmaceutical wastes: carbon-14, tritium, iodine-125, phosphorus-32, sulfur-35, and technecium-99; fuel-fabrication wastes: uranium-235 and -238; and sealed sources: cesium-137, and cobalt-60.

[c]Government (commercial sites accept LLW from non-DOE government agencies for disposal): phosphorus-32, cobalt-60, chromium-51, nickel-63, tritium, and carbon-14.

[d]Hospitals and universities: tritium, carbon-14, iodine-125, phosphorus-32, sulfur-35, rubidium-37, calcium-45, sulfur-35, chromium-51, iridium-192, and technecium-99.

SOURCE: Adapted from U.S. Department of Energy, *The 1987 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites*, National Low-Level Radioactive Waste Management Program, DOE/LLW-69T, December 1988, p. 141.

Figure 4-3—Estimated Annual Generation of Commercial LLW in 1987



Category	Volume (10^3 ft^3)
Class A	1,388
Class B	39
Class C	12
Total	1,449
GTCC*	1

Category	Radioactivity (10^3 Ci)
Class A	26
Class B	67
Class C	177
Total	270
GTCC*	400

* Since the disposal of GTCC waste is the responsibility of the Federal Government, GTCC waste is usually excluded from most discussions about LLW.

SOURCE: U.S. Department of Energy, *The 1987 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites*, National Low-Level Radioactive Waste Management Program, DOE/LLW-69T, December 1988; and Office of Technology Assessment, *An Evaluation of Options for Managing Greater-Than-Class C Low-Level Radioactive Waste*, OTA-BP-O-50, October 1988, p. 43.

cover disposed waste; stability is also important in limiting exposure to an inadvertent intruder. High integrity containers are used for Class B and C waste. (See ch. 5 for more detail on packaging and chs. 3 and 6 for more detail on disposal regulations.)

Class C Waste

The levels of radioactivity in Class C waste are generally 10 to 100 times higher than levels for Class B waste. Packaging and stability requirements for Class C waste are the same as those for Class B waste. Because of its relatively high levels of radioactivity, some Class C waste must also be shielded and handled remotely to avoid excess exposures to workers. To prevent inadvertent exposure to human intruders, Class C waste must be buried at least 16 feet below the Earth's surface or covered with a thick intrusion barrier (e.g., concrete slab). (See ch. 5 for more detail on packaging and chs. 3 and 6 for more detail on disposal regulations.)

Greater-Than-Class C Waste

Greater-than-Class C (GTCC) waste is more radioactive than Class C waste, but less radioactive than spent fuel. GTCC waste is generally not acceptable for near-surface disposal. In the LLRWPAA of 1985, the Federal Government was given the responsibility for the disposal of GTCC waste. The Department of Energy is currently developing an inventory of GTCC waste and evaluating alternative disposal technologies, including disposal in deep-geologic repositories along with commercial spent fuel and defense high-level waste. GTCC waste is now being stored onsite pending a decision about its offsite storage and/or disposal (13).

At present, there are about 15,000 cubic feet of packaged GTCC waste now in storage at several hundred generation sites; an additional 1,400 cubic feet of GTCC waste are generated each year. The radioactivity of this waste is about 5 million curies, or an amount of radioactivity equivalent to all other commercial LLW that has been generated and disposed of to date (13).

SPECIAL CATEGORIES OF LLW

The following categories of LLW do not fall neatly into commercial LLW but can be considered in some way special because of their composition, volume, or unique characteristics.

Mixed LLW

Several studies performed in the mid-1980s indicated that about 3 to 10 percent of all commercial LLW is mixed LLW because it contains both radioactive and chemically hazardous constituents (12). Commercial mixed waste is defined and identified in a document issued jointly by NRC and the Environmental Protection Agency (EPA) in 1987 (19). This waste is produced by a full range of LLW generators (e.g., nuclear power plants, medical and academic institutions, and various industries such as pharmaceutical and biotechnology firms) and waste processors.

As shown in table 4-3, the hazardous constituents in mixed LLW typically include: organic liquids, metallic lead, cadmium, chromates, and waste oils (12). Several of the types of mixed LLW listed in the table have been consolidated into five categories:

1. **Organic liquids**: Organic liquids are produced by a full range of LLW generators. Scintillation fluids, which are used in diagnostic tests and general laboratory counting procedures for environmental and facility monitoring, comprise the largest volume of mixed LLW. These fluids typically contain toluene and xylene. Organic liquids are also generated by industries during the manufacture of sealed sources, pharmaceuticals, radiopharmaceuticals, and diagnostic tests. Industries and nuclear power plants use organic chemicals, such as acetone and chlorofluorocarbons (CFCs), commonly referred to as freon, for cleaning protective clothing, tools, equipment, and instrumentation. Trash can also be contaminated with organic chemicals.
2. **Metallic lead**: Metallic lead becomes radioactively contaminated when it is used to store radioactive materials in a shielded container or to shield workers from radiation exposure during product manufacturing and laboratory research. This lead may be in the form of foil, sheets, bricks, or containers for storage or shipping. If lead is decontaminated, the cleaning solutions containing dissolved lead and radioactive material will also be classified as a mixed LLW.
3. **Cadmium**: Nuclear power plants generate radioactively contaminated cadmium waste when welding rods containing cadmium are used. Equipment with such welds and the

Table 4-3—Summary of Mixed LLW Generation Practices

	GENERATOR COMMUNITY							
	Industrial facilities					Medical/academic institutions		Nuclear power plants
TYPE OF MIXED LLW	Pharmaceutical manufacturing	Biotechnology manufacturing	Other manufacturing	Spent fuel storage	Waste processor	Medical/clinical & research	University nonmedical research	
Liquid scintillation cocktails or fluids	**Laboratory counting procedures**	**Laboratory counting procedures**	**Laboratory counting procedures**	**NA**	**Processing to separate fluid from vials**	**Laboratory counting procedures**	**Laboratory counting procedures**	**Laboratory counting procedures**
Organic chemicals	Residue from research Residue from manufacturing Cleaning of laboratory and process equipment	Spent reagents from experiment Cleaning of laboratory equipment	Residue from research Residue from manufacturing Cleaning of laboratory and process equipment Expired product	NA	NA	NA	Cleaning of laboratory equipment	Cleaning of laboratory equipment Cleaning of contaminated components
Trash with organic chemicals	**NA**	**Used equipment from research**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Lead	Contaminated during use	Contaminated during use	Residue from manufacturing	NA	NA	Contaminated during use	Contaminated during use	Contaminated during use
Lead decontamination solutions	**NA**	**NA**	**NA**	**NA**	**Decontamination of lead shielding**	**NA**	**NA**	**Decontamination of lead shielding**
Waste oil	Oil from contaminated equipment	NA	Oil from radioactive systems/areas	NA	Oil from radioactive systems	NA	Oil from radioactive systems	Oil from radioactive systems Oil from hot shop
Trash with oil	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**Oil from radioactive systems Oil from hot shop**
Chlorofluorocarbon (CFC) solvent	NA	NA	NA	NA	NA	NA	NA	Clothes laundry
CFC concentrates	**NA**	**NA**	**NA**	**NA**	**Clothes laundry Tool decomtamination**	**NA**	**NA**	**Clothes laundry Tool decontamination**
Aqueous corrosive liquids	NA	NA	NA	Cleaning of spent fuel casks Backflush of resin filters	NA	NA	NA	NA
Chromate waste	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**Resin changeouts**
Cadmium waste	NA	NA	NA	NA	NA	NA	NA	Spent welding rods Weld cleaning Equipment decontamination

NA = Not applicable

SOURCE: Rogers & Associates Engineering Corp., "Management Practices and Disposal Concepts For Low Level Radioactive Mixed Waste," RAE 8830 1, contractor report prepared for the Office of Technology Assessment, March 1989, p. 2.17

liquids and solid materials used to clean such equipment may also be contaminated with cadmium. This waste may not be found to be mixed if it passes EPA's EP toxicity test, which tests for leachability.

4. **Chromates**: Some nuclear power plants use chromates to inhibit corrosion in water circulation systems. When the water purification resins are periodically changed, they will be considered mixed wastes if they fail EPA's EP toxicity test.
5. **Waste oils**: When the oil in pumps and other equipment located in radioactive areas is periodically changed, the oil is generally contaminated. Such waste oils and oily trash, principally from radioactively contaminated machine shops, are considered hazardous under some State regulations. EPA is currently making a determination on whether waste oil will be listed as a hazardous waste (see ch. 3).

Until 1985, most commercial mixed LLW was disposed of in NRC-licensed LLW disposal facilities. In the future, disposal facilities for mixed LLW will be licensed by NRC and EPA or by States with NRC/EPA licensing/permitting authority. However, **neither the three currently operating LLW disposal facilities nor any hazardous waste landfills are licensed to accept mixed LLW.** (The only exception is that some waste oils and lead may be accepted at LLW sites if they meet requirements of the individual sites.) The vast majority of commercial mixed LLW that cannot be treated and disposed of as ordinary trash, LLW, or hazardous waste, therefore, will have to remain in storage until mixed LLW disposal facilities are developed by States or compacts. (See chs. 3 and 5 for more detail on this situation.)

Naturally Occurring and Accelerator Produced Radioactive Material (NARM)

NARM includes such naturally occurring material as radium-226 used in some smoke detectors and watch dials, and polonium-210 used in some industrial gauges; NARM also includes accelerator produced radioactive material generated in linear accelerators for use in medical instruments. Twenty-eight States regulate NARM and existing commercial disposal sites can accept such waste. Under Federal law, however, neither the States nor the Federal Government is presently responsible for disposal of NARM.

Other LLW

Some LLW is also generated by certain special projects. Two examples are the decontamination of Unit 2 of the Three Mile Island nuclear power plant and the cleanup operation at West Valley, NY, the site of a no-longer operating commercial spent-fuel reprocessing plant.

COMPARISON OF LLW TO OTHER TYPES OF RADIOACTIVE WASTE

By the end of 1988, the United States had cumulatively generated over 135 million cubic feet of LLW, consisting of 19 million curies, from both commercial and defense activities. Defense activities have generated about 66 percent of this volume and about 74 percent of the radioactivity. These percentages are equivalent to the defense program having generated about twice the volume and three times the radioactivity of commercial LLW.

Commercial LLW and defense LLW include almost 85 percent of the volume of all categories of radioactive waste (including high-level waste, spent fuel, and transuranic waste) generated in this Nation. However, the radioactivity in commercial LLW and defense LLW only contains about 0.1 percent of the total radioactivity in all categories of radioactive waste. As shown in table 4-4, the vast majority of the radioactivity is in the spent fuel generated by 113 operating commercial nuclear power plants.

IMPLICATIONS OF WASTE MINIMIZATION AND TREATMENT TECHNIQUES ON FUTURE WASTE VOLUMES

Although the NRC encourages waste minimization techniques, which eliminate wastes from being generated, and treatment techniques, which reduce the volume of wastes once they are generated (18), waste generators are not required to use any of the techniques noted in box 4-B and described in more detail in chapter 5. The 250 percent increase in LLW disposal costs over the last decade, due to costs associated with new disposal regulations and disposal surcharges established in the LLRWPAA, has been the driving force behind reducing LLW volumes. In fact, between 1980 and 1988 the volume of commercial LLW shipped for disposal has de-

Table 4-4—Cumulative Amounts of Radioactive Waste Generated Through 1988[a]

Waste type	Volumes (in 10^3 ft^3)	Percent	Activity (in 10^6 Ci)	Percent
Low-level waste				
Commercial	46,000	29.3	5	0.02
Defense	87,000	55.5	14	0.06
High-level waste				
Commercial[b]	80	0.05	30	0.2
Defense	13,500	8.6	1,175	5.4
Commercial spent fuel	270	0.17	20,400	94.3
Defense TRU waste	10,000	6.4	4	0.02
Total	156,850	100.02	21,628	100.00

[a] Does not include mill tailings or waste from remedial action projects.

[b] Commercial waste now located at West Valley, NY. Also assumes no commercial reprocessing of spent fuel.

SOURCE: U.S. Department of Energy, DRAFT *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1988, p. 22.

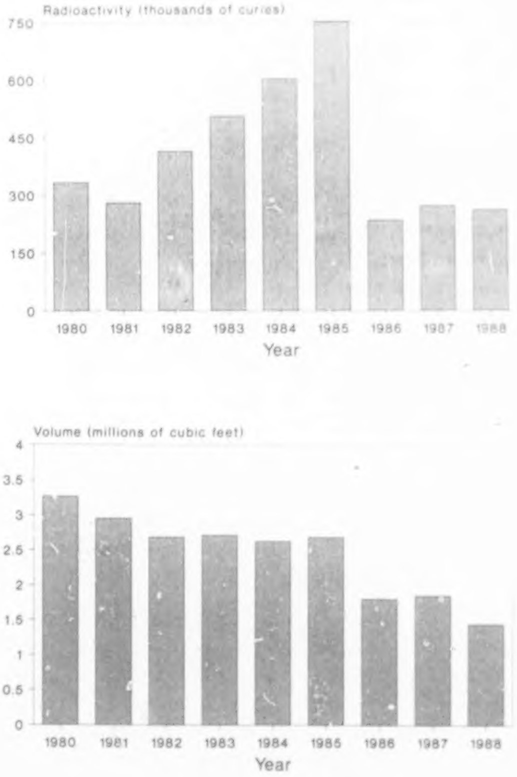
creased by about 55 percent. This trend of decreasing LLW volume is shown in figure 4-4 for the Nation, and in appendix A for each State and compact.

As shown in figure 4-1, the most significant reductions in waste volumes are directly related to notable increases in unit disposal costs (i.e., cost per cubic foot). If trends continue, the volume of LLW shipped for disposal in 1989 should be about the same as in 1988; however, another significant drop in waste volumes will probably come in 1990 when the disposal surcharge doubles from $20 to $40 per cubic foot, as allowed in the LLRWPAA of 1985. If unit disposal costs continue to increase during the 1990s as smaller, more expensive disposal facilities are brought on line, the trend of decreasing LLW volumes shipped for disposal will probably continue. (Disposal costs are discussed in more detail in ch. 6.)

The LLRWPAA of 1985 limits the amount of LLW that will be accepted for disposal at each of the three existing disposal sites. These annual limits are listed in figure 4-5. In addition, volumes of LLW from commercial nuclear power plants cannot exceed about 60 percent of the total limit for all three sites. Due to the increasing use of volume reduction technologies, the average volumes of LLW accepted for disposal over the last 3 years are well within the overall volumetric limitations and within the individual limits and the licensed capacities for all three sites. If present trends continue, it is unlikely that any volumetric limits will be exceeded.

Table 4-5 presents an approach to estimate the potential for further volume reduction if currently

Figure 4-4—Yearly Volumes and Radioactivity of Commercial LLW Shipped for Disposal (1980-1988)



SOURCE: U.S. Department of Energy, DRAFT, *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1989, p. 148.

Box 4-B—Waste Minimization and Treatment Techniques

Several waste minimization and treatment techniques are briefly discussed below. With the exception of the first three techniques listed, these techniques have little effect on reducing the waste's radioactivity.

- **Using nonradioactive substitutes.** In many industrial and research applications, nonradioactive material can be effectively substituted for radioactive materials. If radioactive material must be used, it may be possible to use smaller amounts of material or isotopes that decay more rapidly.
- **Improving the management of radioactive materials.** Volumes of radioactive material may be reduced through better scheduling of material use, reducing excess purchases of radioactive material, and coordinating purchases through a "clearinghouse." Simply segregating radioactive from nonradioactive material can also lead to significant volume reductions.
- **Storing radioactive material to allow decay.** Many radionuclides in LLW decay to lower levels within a relatively short time. By storing wastes at their generation sites for a few months to a few years, the radioactivity may be reduced enough to allow its disposal with other less radioactive wastes or with municipal waste, should the radioactivity be below background levels.
- **Compacting and shredding dry wastes.** Compactors can achieve a 5-fold to 10-fold volume reduction, depending on the size of the unit and the type of waste. These units can reduce the height of 55-gallon drums of waste by 60 to 90 percent within just a few minutes simply by crushing them into large "hockey pucks" (6, 8). Shredders can be used with or without compaction to reduce waste volumes.
- **Decontaminating materials.** LLW generators have been successful in decontaminating large pieces of equipment, tools, glassware, and clothing so that they can be reused.
- **Incinerating wastes.** Combustible liquids and solid wastes can be incinerated with a 20-fold to 30-fold reduction in volume. For example, about 80 percent of the dry LLW (i.e., trash) from an average nuclear power plant is combustible (4). At present, about 100 small on-site incinerators are used mostly by hospitals, research laboratories, and universities. No commercial incinerator, however, is presently available for offsite LLW incineration.

SOURCE: Office of Technology Assessment, 1989.

available waste minimization and treatment techniques are more widely applied. The approach is based on maximizing decontamination with material reuse and future incineration.

Utility waste accounted for 58 percent (840,000 cubic feet) of the Nation's LLW volume in 1988 (1,440,000 cubic feet). Approximately 43 percent (360,000 cubic feet) of this waste is combustible. A substantial portion of the remaining 57 percent (480,000 cubic feet) of utility LLW consists of metallic material that, in many cases, could be decontaminated. If it is conservatively assumed that half of the 57 percent could be decontaminated, 240,000 cubic feet of waste would be added to the 360,000 cubic feet of combustible waste, totaling 600,000 cubic feet of volume reduction. Therefore, **nuclear utilities alone could be responsible for reducing the total LLW volume by 42 percent from their 1988 volume level. Industrial waste generators,** which generated 35 percent of the Nation's LLW in 1988 and generate similar waste products, **could also increase their use of these two techniques, potentially increasing the total percentage of volume reduction to around 50 percent.**[6] Because of the uncertainty of costs being tied closely enough to volume versus radioactivity to drive volume reduction practices, a range of 40 to 50 percent reduction in waste volumes is estimated.

Volume reductions could also result from BRC limits being finalized (see ch. 3) which may enable some dry wastes that are now classified as Class A to be disposed of in a municipal landfill or hazardous waste landfill, depending on its hazardous characteristics. Likewise, liquid BRC LLW not containing hazardous waste constituents may possibly be disposed of through a municipal sewer system. The nuclear utility industry estimates that a BRC limit of

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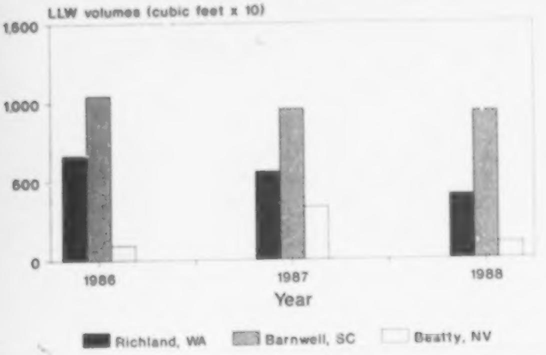
[6] This degree of volume reduction will only occur if disposal fees are based primarily on volume. In the future, site operators could decide to base fees only on radioactivity, which would remove generators' incentives to reduce volume.

Figure 4-5—Volumes of Commercial LLW Disposal in 1986, 1987, and 1988



Disposal site	LLW volumes (10³ cubic feet) Annual limit	Licensed capacity	Volume used
Richland, WA	1,400	52,700	10,790
Barnwell, SC	1,200	34,400	20,684
Beatty, NV	200	4,900	3,990
Total	2,800	92,000	35,458

SOURCE: U.S. Department of Energy, DRAFT, *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1989, p. 157. Data on licensed capacity taken from U.S. Department of Energy, *The 1987 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites*, National Low-Level Radioactive Waste Management Program, DOE/LLW-66T, December 1988.

15 millirems per year could decrease its LLW volume by as much as 30 percent.[7]

UNDERSTANDING RADIATION AND ITS HEALTH EFFECTS

Radiation is a natural phenomenon of our environment that has been present since life evolved. Ionizing radiation is a form of energy generated by the activity of atoms, which are the basic building blocks of matter. Some atoms are unstable and spontaneously change into another form. An unstable atom is said to be **radioactive** and the process by which it changes into a new atom is called **radioactive decay**. More specifically, an unstable atom releases excess energy when an electron is lost or gained. This energy is in the form of waves or fast-moving particles. An atom that spontaneously produces radiation is called a **radionuclide**. Within a certain period, called a **half-life**, half of an unstable atom decays and gives off radiation. All radionuclides have a known half-life. Half-lives range from fractions of a second to billions of years. Refer to table 4-2 for the half-lives of the principal radionuclides found in commercial LLW.

Table 4-5—Projected Volume Reduction of Commercial LLW

	Volume (cubic feet) (based on 1988 shipment data)
LLW volume shipped for disposal	
Utility (58%)	840,000
Industrial (35%)	500,000
Other (7%)	100,000
Total	1,440,000
	Possible volume reduction (cubic feet)
Utility	
Combustible[a]	360,000
Recyclable	240,000
Total utility reduction (42% of total shipped)	600,000
Industry	
Combustable + recyclable = 20% reduction[b] (7% of total shipped)	100,000
Possible total volume reduction (49% total volume reduction)	700,000

[a]Figure deduced from Electric Power Research Institute, *Radwaste Generation Survey Update*, prepared by Analytical Resources, Inc., Sinking Spring, PA, February 1988.

[b]Conservative estimate representing a 20% reduction of industrial disposal of LLW.

SOURCE: Office of Technology Assessment, 1989.

Sources of Ionizing Radiation

An individual is routinely exposed to ionizing radiation from several natural sources: cosmic rays from the sun and stars, natural radioactive elements from the earth (e.g., radium, uranium, and potassium), and naturally occurring radionuclides in the human body (e.g., carbon-14). Internal exposure can come from naturally occurring radioactive elements in food, water, and air. Milk, for example, contains potassium-40, which emits a small but measurable amount of radiation. The levels of natural background radiation vary greatly from location to location. For example, in Denver, CO, the levels of cosmic radiation are twice as high as they are in Washington, DC, because of Denver's higher elevation. Furthermore, there are large regional differences in background radiation due to minerals in the ground at a particular location. For example, the background level in certain parts of Colorado can be three times higher than Gulf Coast States such as Mississippi and Alabama. Increased exposure can also result from living in a brick or stone house versus wood due to radon gas released from stone and brick. On average, all natural sources of radiation together represent about 82 percent of all radiation an individual receives (11). (See figure 4-6.)

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[7] Comment made by Patricia Robinson, LLW Program Manager, Electric Power Research Institute, at the *Fifth Annual Decisionmakers' Forum—Low-Level Radioactive Waste Management: The Available Options and Costs*, Wild Dunes, South Carolina, June 6-8, 1989.

Individuals are also exposed to man-made sources of ionizing radiation, such as radiotherapy for disease and X-rays for medical and dental tests. As with natural sources of radiation, the level of radiation received by man-made sources varies greatly with the individual. For example, the radiation from diagnostic X-rays received for a lower gastrointestinal test is almost 10 times greater than that received for a chest X-ray (8). On average, these man-made sources of radiation for medical uses represent about 15 percent of all radiation an individual receives (11). (See figure 4-6.)

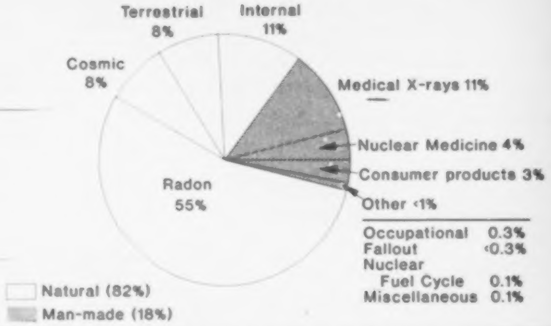
The remaining amount of ionizing radiation comes from industrial uses of radioactive materials, emissions from certain consumer products, radiation from fallout of previously conducted above-ground tests of nuclear weapons, nuclear power plant operations, and miscellaneous activities. The amount of radiation from all of these sources is estimated to be about 3 percent of the total (11). The amount of radiation from LLW is some fraction of 1 percent (11). (See figure 4-6.)

The Nature of Ionizing Radiation

There are three types of ionizing radiation—alpha particles, beta particles, and gamma rays or photons—that result from the decay of radionuclides. The radioactivity of radionuclides is measured in units called **curies**, with 1 curie describing the radiation from 1 gram of radium for 1 second, or about 37 billion disintegrations per second.[8]

Alpha radiation consists of positively charged, highly energized particles that rapidly lose energy when passing through matter. They are emitted from naturally occurring radioactive elements, such as radium and uranium, and from man-made elements such as plutonium. Alpha particles are larger and heavier than the particles of beta radiation. Alpha particles can be stopped by a sheet of paper or by human skin so that holding a piece of plutonium in your hand would be perfectly safe. If ingested or inhaled, however, alpha particles would damage internal tissues with grave consequences (see section on "Biological Responses to Radiation"). Inhalation of even tiny amounts of plutonium can cause lung cancer. Low-level radioactive waste generally does not contain alpha-producing radionuclides.

Figure 4-6—The Percentage Contribution of Various Radiation Sources to the Total Average Effective Dose Equivalent in the U.S. Population



SOURCE: National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposures of the Population of the United States*, NCRP Report 93, Bethesda, MD, 1987, p. 55.

Beta radiation consists of smaller particles that travel more quickly in air and can penetrate several cell layers of skin. Beta radiation can be reduced or stopped by a layer of clothing or through the use of a few millimeters of aluminum, glass, or plastic shielding. Beta-emitting radionuclides are found in most LLW.

Gamma radiation is in a wave form like light and X-rays and consists of photons—small packets of energy that can travel great distances and penetrate matter. Gamma rays can pass through the human body or can be absorbed by tissue or bone. Three feet of concrete or 2 inches of lead will reduce or stop 90 percent of typical gamma radiation. Gamma photons are used in cancer treatment to destroy the cells of a tumor without causing major damage to healthy cells nearby. Gamma-emitting radionuclides are found in most LLW.

Radionuclides in LLW that emit both beta particles and gamma photons are classified as either beta emitters or gamma emitters according to which emitter is biologically more harmful. For example, cobalt-60 is referred to as a gamma emitter because the accompanying beta radiation is biologically less damaging.

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[8] The international unit for radioactivity is the becquerel (Bq), which equals one disintegration per second.

Measuring Radiation

The amount of ionization that a given quantity of radiation produces is the **exposure**. A common unit for measuring exposure is the roentgen; one roentgen is 2.58×10^{-4} coulombs per kilogram of air.

When radiation penetrates biological material it gives up its energy in a series of collisions or other interactions with the atoms of the material being irradiated. The consequences of these interactions may be the dislocation of atoms, the breaking of chemical bonds, or the loss of electrons. These molecular alterations may in turn impair the biological functions of the irradiated material. The amount of energy deposited in the material is the **absorbed dose**. A common unit used to measure absorbed dose is the **rad**, an abbreviation for radiation absorbed dose.[9] Note that exposure and absorbed dose are very different. Exposure describes a property of the radiation, while the absorbed dose describes something that happens to a particular material when the radiation is absorbed.

Biological Responses to Radiation

The amount of biological damage resulting from a particular absorbed dose is the **dose equivalent**. The dose equivalent depends on the kind, amount, and rate of the radiation; on the nature of the organism exposed; on the organism's age, sex, state of health, and surroundings; and on the particular biological effect being considered (10).

The dose equivalent is often referred to as simply the **dose**, when the absorbed dose is equivalent to the dose equivalent. This equivalence is generally true for X-rays, gamma rays, and for most beta particles (10). The major exception is alpha radiation, which can lead to more serious biological damage. Once alpha particles are absorbed by tissue, their large size and density and the slow speed at which they travel results in more energy being released in a smaller area. The radiation is, therefore, more concentrated and causes more damage. Since this study primarily deals with beta rays and gamma rays, the term dose is used for dose equivalent. Dose is measured in **rems**, or "roentgen equivalent man."[10]

The average annual whole body dose to a person in the United States from natural and man-made sources is about 360 millirems (11).[11] An actual dose to any given individual could vary widely, however. Over the course of a lifetime, an individual may accumulate doses from background exposures of between 5 and 10 rems (6).

An excessive dose of radiation can result in somatic damage (i.e., damage to the cells of the body that compose the tissues and organs) and in genetic damage that can become hereditary. Somatic damage is most common in cells that divide more frequently, such as blood-forming cells of the bone marrow and cells that line the intestinal wall (10). The body concentrates certain radionuclides selectively in one or another organ (3). Iodine-129 and iodine-131, for example, concentrate in the thyroid; strontium-90 concentrates in the bone; and nickel-59 concentrates in the intestine. Radiation damage to these kinds of cells are caused mainly by the acute (short-term) effects of large doses of radiation.

Embryos are particularly sensitive to somatic effects from radiation. They are more susceptible to malformities and death than adults (6).

Cancer can result if cell reproduction is impaired by radiation and uncontrolled growth occurs. Leukemia and lung, breast, and thyroid cancers appear more common than other types of cancer due to radiation (6).

Radiation doses can also cause two types of genetic damage—whole chromosome damage and gene mutation. With whole chromosome damage, the number of chromosomes in a genetic cell may change or a chromosome may break, in which case the broken pieces may reattach in a way that leaves the chromosome's function impaired. With gene mutation, a gene may change such that the individual inheriting the gene demonstrates an observable malfunction such as mental retardation, or, more drastically, the gene may be so damaged that it cannot reproduce itself (10). Table 4-6 gives the types of effects that can be expected from certain ranges of radiation doses. Data have also been collected on actual doses that individuals have received on average from certain radiation events (e.g., doses to people from nuclear weapon tests, the dose to nuclear power plant workers on average, and the dose to survivors of the Japanese A-bomb explosions.

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[9] The international unit for absorbed dose is the gray (Gy), which is equal to one joule per kilogram. The rad is equal to 10^{-2} Gy.

[10] The international unit for dose is the sievert (Sv); a rem is equal to 10^{-2} Sv.

[11] A millirem is a one-thousandth of a rem (10^{-3} rem).

The Chernobyl reactor accident has provided invaluable information on health effects. As a result of Chernobyl, 237 individuals had radiation sickness in the Soviet Union. Of these 237 people, 31 died from the dose received. Of the 50,000 people who received 50 rads or more, 4,000 apparently received an average of 200 rads. Experts predict that over the next decade the fatal leukemia risk of this group of 4,000 is projected to increase by about 150 percent (1). The irradiated population is also at risk for genetic disorders in future generations. Up to 1,500 additional cases of genetic damage may be added to the 35 to 40 million normally expected in the population of Europe and the Soviet Union (1). Experts also predict a doubling of cases of radiation-induced severe mental retardation in children who lived in the area around Chernobyl (1).

Other actual radiation effects were seen in a group of women who painted radium watch dials in the 1920s. These women pointed their paint brushes with their lips to paint the fine numerals of the watch faces. By 1950, 41 deaths had been reported as a result of bone destruction and blood disorders caused by the radium absorbed in bone marrow (10).

Uncertainties in Estimating Health Effects From Low Radiation Doses

Some experts predict that small radiation doses given at very low dose rates do not necessarily produce an effect that is linearly proportional to the radiation dose (6). Furthermore, a given radiation dose delivered over a long period is generally less severe than the same dose delivered acutely (6). However, for several reasons it is difficult to precisely measure health effects from low radiation doses.

One reason is that health effect estimates are frequently calculated by extrapolating from measurements made at high exposures. Because health effect and dose are not linear, these calculations may not reflect actual effects at low dose levels. A conservative approach used by many experts is to assume a no-threshold linear model, with risk increasing linearly as dose increases (6).

Table 4-6—Acute Health Effects Estimated From Whole Body Irradiation

Dose (rems)	Heath effect
5-20	Possible late effect; possible chromosomal aberrations
25-100	Blood changes
>50	Temporary sterility in males (>100rem = 1 year duration)
100	Double the incidence of genetic defects which is normally expected
100-200	Malaise, vomiting, diarrhea, and tiredness in a few hours; reduction in infection resistance, possible bone growth retardation in children.
200-300	Serious radiation sickness; bone marrow syndrome; hemorrhage; $LD_{10\text{-}35/30}$
>300	Permanent sterility in females
300-400	Resulting loss of blood defenses and vascular integrity; electrolyte imbalance; marrow/intestine destruction; $LD_{50\text{-}70/30}$
400-1,000	Acute illness, early death; $LD_{60\text{-}95/30}$
1,000-5,000	Acute illness, early death in days; intestinal syndrome $LD_{100/10}$
>5,000	Acute illness; death, early death in hours to days; central nervous syndrome; $LD_{100/2}$

*Lethal dose to percentage of the population in number of days (for example, $LD_{10\text{-}35/30}$ = lethal dose in 10 percent to 35 percent of the population in 30 days.

SOURCE: Adapted from Marvin Goldman, "Ionizing Radiation and Its Risks," *The Western Journal of Medicine*, vol. 137, No. 6, December 1982, pp. 540-547, and Gilbert W. Beebe, "Ionizing Radiation and Health," *American Scientist*, vol. 70, No. 1, January-February 1982, pp. 35-44.

Another reason is the difficulty of tracing a particular health effect to a particular low radiation dose. For example, if a person contracted lung cancer, it would be very difficult to determine the cause of the cancer if he/she lives in a house with an elevated radon level, has had multiple dental and medical tests using radionuclides in some form, and works in a nuclear power plant. It would be difficult to know whether all the sources of radiation were responsible for the cancer, or whether one source was more responsible than another.

Compounded environmental cancer risks from chemicals further complicate health matters. In the lung cancer example above, if the person smoked it would be extremely difficult to estimate what percentage each of the radiation doses and the chemical dose from smoking is responsible for the cancer. One source of dose may mask another or may exacerbate the overall impact to the individual. This potential synergism between physical risk from ionizing radiation and the potential environmental cancer risks from chemicals is not well understood (6).

Another problem with estimating low-dose health effects is the radiation latency factor—the time from a brief exposure to the first appearance of disease. For example, the minimal latent period for leukemia and bone cancer is 2 to 4 years. It may be 10 or more years for other types of cancer (2). The incidence of leukemia among Japanese A-bomb survivors reached a peak 6 years after the explosion. Most solid tumors require 10 to 20 years to develop (10).

A further complication is that much of our data is based on animal studies (8). For humans, the full significance of age and sex on cancer response is not known, nor is the significance of biologic factors such as immune competence, hormonal status, capacity for DNA repair, and genetic composition.

Finally, conducting a valid epidemiologic study is difficult because of too small an exposure group and because of the time necessary to conduct a study. In most cases of radiation exposure events, the population size is too small to conduct a study where statistically significant risk estimates can be calculated. The exceptions are victims and survivors of the Japanese A-bombs and Chernobyl accident. Even with these two events, health effect estimates for the low-dose population are difficult to calculate because of the competing unrelated sources of radiation exposure and environmental risks from chemicals.

With respect to LLW disposal, no actual data on radiation exposures to the general public from past disposal practices exists. The collective dose to nearby residents is calculated to be well below the operating limits established by the Nuclear Regulatory Commission (NRC). Furthermore, no member of the public is known to have received a measurable radiation dose from disposal practices. Workers at the disposal sites during the operational period of the site receive the greatest dose. Workers wear radiation detection devices to ensure that the exposure they receive is below the allowable limits set by NRC. NRC requires that at all times exposure be kept as low as reasonably achievable (ALARA).

The ALARA concept developed from the scientific consensus that there is no clearly definable threshold level of exposure. The ALARA concept requires that the cost of achieving an incremental reduction below regulatory limits be weighed against the benefit received in terms of reduced occupational or population exposures (3). At LLW disposal sites, ALARA has influenced:

- imposition of engineered controls and barriers to limit effluent releases,
- the improvement of instrumentation to validate lower objectives for allowable concentrations in conjunction with enhanced monitoring of the workplace and the surrounding regions, and
- evolution of radiation protection programs in the facilities designed specifically to achieve ALARA conditions (3).

A Department of Energy study estimates that the highest dose rate to the maximally exposed member of the public from a properly functioning LLW disposal facility would be 10 millirems per year (15). The collective dose rate to nearby residents would be much lower. If a LLW disposal facility had a major failure, it is estimated that a maximally exposed member of the public could receive as much as 500 millirems per year (8). This dose rate is equal to the limit that a worker is allowed to receive within 1 year in the unrestricted areas of a site (10 CFR Part 20). In a restricted area, a worker may receive a dose an order of magnitude higher. Even at the 500 millirem dose rate, however, the facility would have to be remediated immediately; therefore, this dose rate would not be expected to continue.

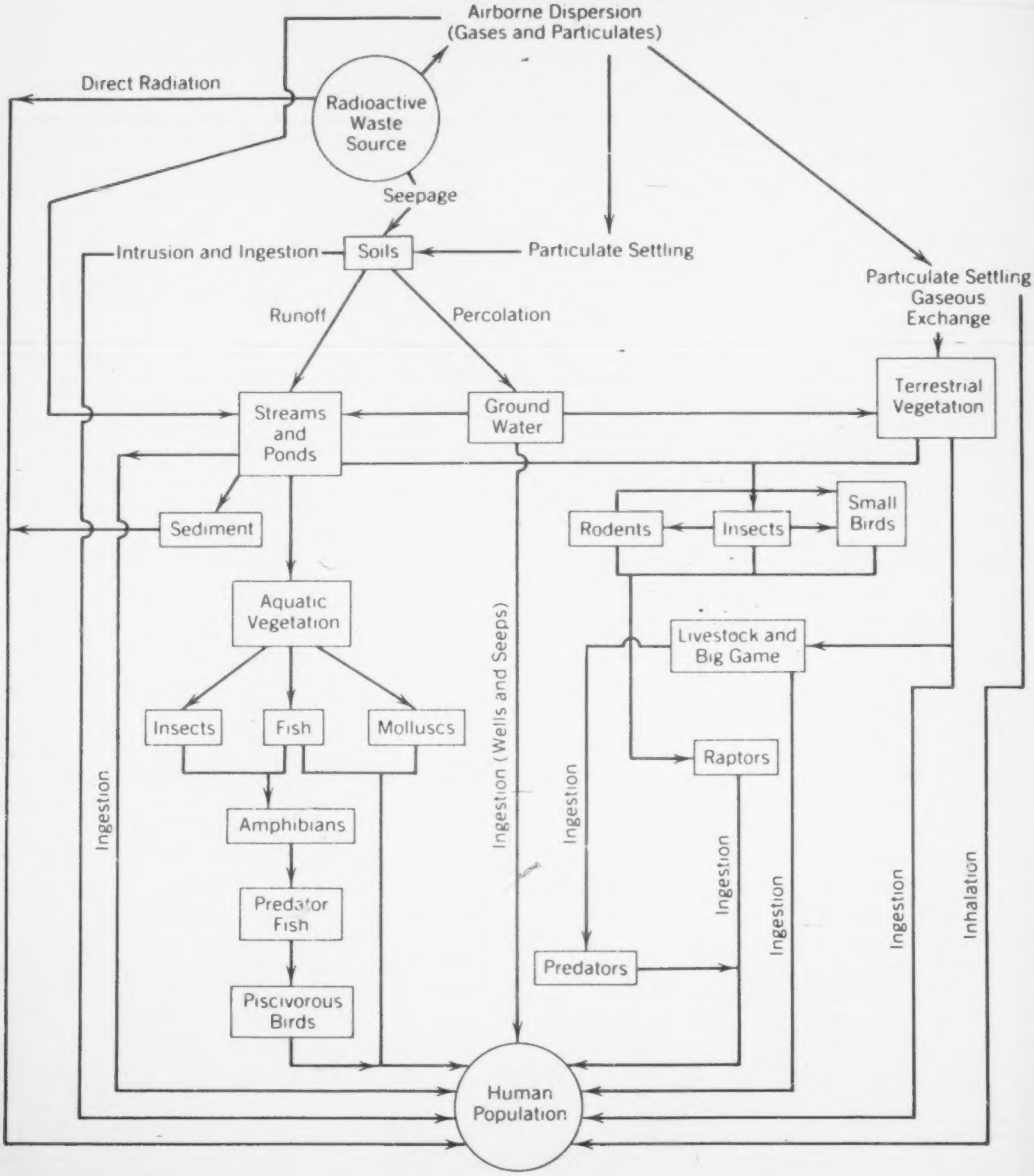
Migration Pathways and Mechanisms of Radiation Exposure

Figure 4-7 outlines the migration pathways and mechanisms of human exposure from radionuclides in a LLW disposal site. These pathways include seepage or runoff from surface water, groundwater transport, and atmospheric transport. Computer analyses indicate that the groundwater is the major pathway at humid sites (8). No single pathway appears to be dominant for dry sites.

The primary mechanisms for human exposure include:

- direct radiation of individuals near the source or near disposed material;
- inhalation of emissions dispersed directly into the air;
- direct ingestion of groundwater and/or surface water;
- ingestion of contaminated vegetation on which particulates have settled, or where gaseous exchange has occurred, or which have grown in concentrated soils; and
- ingestion of fauna (e.g., livestock, fish) in the food chain that have ingested and concentrated

Figure 4-7—Pathway Analysis to Biota and Man: Generation and Disposal Locations on Common Site


Airborne Dispersion (Gases and Particulates)
Direct Radiation
Radioactive Waste Source
Seepage
Intrusion and Ingestion
Soils
Particulate Settling
Particulate Settling Gaseous Exchange
Runoff
Percolation
Terrestrial Vegetation
Streams and Ponds
Ground Water
Small Birds
Rodents
Insects
Sediment
Aquatic Vegetation
Livestock and Big Game
Ingestion (Wells and Seeps)
Insects
Fish
Molluscs
Raptors
Ingestion
Amphibians
Predator Fish
Piscivorous Birds
Predators
Inhalation
Human Population

SOURCE: Robert E. Berlin and Catherine S. Stanton, *Radioactive Waste Management* (New York, NY: John Wiley & Sons, Inc., 1989), p. 128.

radionuclides from a lower species in the chain. (3)

As noted above, the annual dose to an individual would likely not exceed 10 millirems for a properly operating facility and would not exceed 500 millirems in case of an accident. NRC sets the annual dose limit of a LLW disposal site at 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ (10 CFR Part 61). Some States have set their site annual dose limits much lower—at 1 millirem in the Central Midwest Compact and at background levels for the Appalachian Compact (see ch. 2). Releases that would result in doses above these levels would require immediate remediation.

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Chapter 5

Current and Emerging LLW Minimization and Treatment Techniques

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Chapter 5

Current and Emerging LLW Minimization and Treatment Techniques

INTRODUCTION

The management of low-level radioactive waste (LLW), including mixed LLW, has three main steps: waste minimization, treatment, and disposal. Waste minimization and treatment techniques are reviewed here, while disposal technologies are discussed in chapter 6.

We define waste minimization as in-plant practices that reduce, avoid, or eliminate the generation of harmful waste so as to reduce risks to human health and the environment. Waste minimization, therefore, is applied to the pre-generation of waste. Treatment, in contrast, is applied to the post-generation of waste, but before the waste is disposed. Treatment is defined in the Resource Conservation and Recovery Act (RCRA)[1], Section 1004, to mean

> . . . any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste nonhazardous, safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.

We broaden this definition to include techniques that facilitate the overall management of LLW, but may not be defined as treatment by the Environmental Protection Agency (EPA). These techniques include waste decontamination, storing radioactive material for decay, compaction, shredding, incineration, and waste stabilization.

Since 1980, escalating LLW disposal costs (see ch. 6) have forced the increased use of waste minimization and treatment techniques. In the future, these techniques will likely continue to play a significant role until disposal costs stabilize.

The problem of managing *mixed* LLW—waste that contains both radioactive and hazardous constituents—has also increased the use of waste minimization and treatment techniques. Since no disposal option has been available for this waste since 1985, mixed LLW generators continue to look for techniques to avoid generating the waste. When the waste's initial generation cannot be avoided, these generators use techniques to treat the waste so that it is *either* solely radioactive or solely hazardous. The generator can then ship the waste to either a LLW disposal site or a hazardous waste landfill. Furthermore, under EPA regulations, a mixed LLW generator is required to treat the hazardous constituent in the waste so that a specified treatment standard is followed. However, the facility necessary to meet these standards is often inaccessible or nonexistent.[2] Once EPA has fully developed and begins to enforce these standards, waste generators will pressure industry to build the necessary facilities to meet the standards, and the use of waste minimization and treatment techniques will further increase.

From a reducing risk standpoint, waste minimization and treatment techniques are often more critical for mixed LLW than for nonmixed LLW. The hazardous constituents (e.g., organic chemicals) in mixed LLW are often more likely to migrate in a disposal site than are the radionuclides. Furthermore, while radionuclides decay over a set time period, hazardous constituents may not degrade significantly. As a result, EPA requires that a certain treatment standard be met for a particular hazardous constituent before it is disposed.

With respect to waste minimization, substitution techniques can eliminate or drastically reduce the amount of radioactive material used, and in-plant processes can be modified to reduce the quantity of waste generated. Waste treatment techniques are used to make LLW that is generated, including mixed LLW, safer for storage, shipment, and disposal. Generators also frequently use treatment techniques to reduce their handling, shipping, storage, and disposal costs.

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[1] Public Law 94-580, Oct. 21, 1976.

[2] Furthermore, EPA has yet to develop treatment standards for some mixed LLW, as is discussed below in the section on "Types of Mixed LLW for Which No Waste Minimization or Treatment Techniques Are Currently Available."

Table 5-1—Summary of Mixed LLW Generation Practices

	GENERATOR COMMUNITY							
	Industrial facilities					Medical/academic institutions		Nuclear power plants
TYPE OF MIXED LLW	Pharmaceutical manufacturing	Biotechnology manufacturing	Other manufacturing	Spent fuel storage	Waste processor	Medical/clinical & research	University nonmedical research	
Liquid scintillation cocktails or fluids	Substitute environmentally benign fluids Store for decay Declare BRC Revise procedures Long-term storage	Store for decay Declare BRC	Substitute environmentally benign fluids Store for decay Declare BRC	NA	Liquid released as nonradioactive waste	Substitute environmentally benign fluids Store for decay Declare BRC	Substitute environmentally benign fluids Store for decay Declare BRC Revise procedures Long-term storage	Reclaim solvent and incinerate Substitute environmentally benign fluids Manage as radioactive waste Long-term storage
Organic chemicals	Substitute nonhazardous materials Revise procedures Store for decay Long-term storage	Justify use Store for decay	Substitute environmentally benign fluids Store for decay Improve inventory practices Long-term storage	NA	NA	NA	Education Notification prior to use Justify use Long-term storage	Recycle Substitute other materials Manage as radioactive waste Long-term storage
Trash with organic chemicals	NA	Store for decay	NA	NA	NA	NA	NA	NA
Lead	Use nonlead containers Long-term storage	Decontaminate	Long-term storage	NA	Decontaminate Use coated lead	Use nonlead containers Minimize use of containers Long-term storage	Use nonlead containers Minimize use of containers Long-term storage	Decontaminate (onsite or at waste processor) Long-term storage
Lead decontamination solutions	NA	NA	NA	NA	Solidify	NA	NA	NA
Waste oil	NA	NA	Solidification	NA	Filtration Solidification Incineration	NA	Long-term storage	Filtration Solidification Incineration
Trash with oil	NA	NA	NA	NA	NA	NA	NA	Manage as radioactive waste
Chlorofluorocarbon (CFC) solvent	NA	NA	NA	NA	NA	NA	NA	Manage as radioactive waste Recycle solvent Long-term storage
CFC concentrates	NA	NA	NA	NA	Long-term storage	NA	NA	Manage as radioactive waste Delist Long-term storage
Aqueous corrosive liquids	NA	NA	NA	Long-term storage	NA	NA	NA	NA
Chromate waste	NA	NA	NA	NA	NA	NA	NA	Manage as radioactive waste
Cadmium waste	NA	NA	NA	NA	NA	NA	NA	Delist by solidification Manage as radioactive waste

NA = Not applicable.

SOURCE: Rogers & Associates Engineering Corp., "Management Practices and Disposal Concepts For Low-Level Radioactive Mixed Waste," RAE-8830-1, contractor report prepared for the Office of Technology Assessment, March 1989, p. 2-17.

Table 5-1 lists all minimization and treatment techniques currently in use for all 12 known types of mixed LLW, which are discussed in chapter 4. This table compliments table 4-3 which lists the practice(s) responsible for generating these mixed LLW types. Where the phrase "long-term storage" appears on table 5-1, either a minimization and/or treatment technique used at another facility needs to be transferred or such a technique is currently unavailable. Examples of such cases are made in the following sections.

Most of the minimization and treatment techniques discussed are applicable to nonmixed radioactive LLW as well as mixed LLW. However, more examples of techniques relating to mixed LLW have been chosen to illustrate current problems associated with managing mixed LLW and to provide some possible solutions. Furthermore, mixed LLW examples can encourage technical and information transfer between generating communities—something that is not fully occurring today.

WASTE MINIMIZATION TECHNIQUES

Material Substitution

Generators use material substitution to avoid or reduce their use of radioactive material and, in turn, their generation of LLW and mixed LLW. Material substitution is used extensively on scintillation vials, which are used in a wide variety of industrial and medical research procedures. These vials are glass or plastic and often contain an organic chemical solution (e.g., toluene or xylene, both listed as hazardous under RCRA) and a radioactive tracer (e.g., carbon-14, tritium, and to a lesser degree sulfur-35, phosphorus-32, and iodine-125). The waste scintillation liquid is a mixed LLW if:

1. the liquid is RCRA-hazardous, and
2. the radionuclides are other than tritium or carbon-14, or
3. if the amount of tritium or carbon-14 is greater than the NRC limit of 0.05 microcuries per gram of scintillation liquid (10 CFR Part 20.303-20.306).

Scintillation liquids are the largest contributor to the overall volume of mixed LLW generated in the United States. By substituting a nonradioactive tracer (e.g., enzymes and fluorescent labels) for the radioactive tracer, a generator not only eliminates producing a radioactive waste but also a mixed LLW. In such cases, the liquid waste is defined only as a hazardous waste. Procedures using this substitution technique often lead to equivalent or superior results (32, 10).

A waste generator can also choose to substitute its RCRA-listed hazardous scintillation liquid with a non-RCRA listed liquid—often referred to as an "environmentally benign" or biodegradable scintillation liquid (20). As organic-based compounds, these environmentally benign liquids are composed of large organic molecules that are nonhazardous. Once released into the environment, microbial and bacterial activity can destroy these compounds without production of hazardous constituents (20).

At some facilities, environmentally benign scintillation vials are now required for all new research at some facilities. If a generator does not want to use them, the burden is on the generator to justify why a RCRA-hazardous fluid is essential for the procedure. There are cases where this justification can be made. For example, it may not be scientifically prudent to switch vials in the middle of a long-term experiment. Some generators also claim that the environmentally benign liquids are not completely interchangeable with the toluene and xylene liquids (25). In some cases, equipment or procedures need to be changed to use the environmentally benign liquids. In other cases, the environmentally benign liquids may be incompatible with other materials or processes used in the experiment or study. A major reason why some generators want to avoid switching to environmentally benign liquids is that they are simply accustomed to using the toluene and xylene liquids and do not want to learn new procedures (20). Finally, one facility reported that they were not confident that the environmentally benign vials were in fact benign (20).

In cases where environmentally benign vials are appropriate, there are great advantages. The liquid waste would be regulated as only radioactive if it passed the EPA hazardous characteristic tests. A mixed LLW stream, therefore, would be avoided.

Finally, in some cases it may be possible to use both substitution techniques—a nonradioactive tracer and an environmentally benign scintillation liquid—

resulting in neither a mixed LLW nor a radioactive waste. Generators, in turn, could either send the waste to an incinerator or, if permitted by their license and local permits, release the material to sanitary sewer systems.

Another example of a material substitution that eliminates a mixed LLW stream is in the corrosion inhibitor used in nuclear power plants' cooling systems. A hexavalent chromate, which is RCRA-listed as hazardous, has often been used to stop pipes from corroding. Several plants have replaced this type of chromate with a nonhazardous chemical[3] and thus are no longer generating a mixed LLW (20).

Dry cleaning of contaminated clothing can also generate mixed LLW. Waste generators (e.g., nuclear utilities) will dry clean some of their protective clothing (e.g., coveralls) that is slightly radioactive so that it can be re-used. Chlorofluorocarbon (CFC) solvents, often referred to as freon, are used in dry cleaning because of their degreasing capability and are RCRA-listed as a hazardous waste. When the cleaning solution has to be changed, a mixed LLW is produced in the form of sludge and used filters. Several utilities have switched to a water-based laundry service so that hazardous chemicals are eliminated and only nonmixed LLW is produced (20).

Good Housekeeping Practices

Especially for biomedical and medical research institutions, it is possible to reduce the quantities of radioactive material used by improving the scheduling of practices that use radioactive material, reducing excess purchases of radioactive material, and coordinating purchases through a clearinghouse. Education of organic chemical users, for example, has helped sensitize them to avoid generating of mixed LLW. Organic chemicals are often used to clean radioactively contaminated equipment, but users are encouraged to consider alternative cleanup methods.

Good housekeeping practices can also improve technical procedures so that liquid wastes and solid wastes are minimized. With respect to liquid wastes, generators use a variety of techniques to minimize their production and to concentrate them when they are produced. Nuclear utilities, for example, have made small improvements that have resulted in large reductions in the quantity and type of liquid wastes generated. These improvements include:

- minimizing the use of chemicals that increase the quantity of radioactive corrosion products in the liquid cooling system, and
- identifying and stopping leaks in the cooling system so that the amount of contaminated material generated is further reduced (20).

For solid wastes, LLW generators use techniques to ensure that material that does not have to be exposed to radioactivity remains uncontaminated. Contaminated lead is a good example of a solid waste that generators are trying to eliminate, primarily because it is a mixed LLW. Pharmaceutical companies, for example, store neutron-activated stainless steel tubes, which are used to manufacture pharmaceuticals, in underwater storage pools (20). These companies add lead to the aluminum storage cans to ensure that the cans will not be buoyant. The inside of the cans can become contaminated with various radioisotopes. To avoid generating this mixed LLW, companies are replacing the lead with high-density, nonhazardous material (e.g., steel).

Lead is also used in manufacturing shielded isotope shipping containers. These containers typically have a cavity inside for holding a bottle. At times the radioisotope in the bottle can spill and contaminate the lead container. This mixed LLW can be avoided by either using a container that is not made of lead or by placing the bottle in a plastic bag before it is inserted into the lead container.

Lead is also used as shielding in the form of foil, bricks, or sheets. To ensure that this lead does not become contaminated, some generators cover it with a plastic-like substance such as herculon (20).

TREATMENT TECHNIQUES

It is not always possible to use material substitution or a good housekeeping practice to avoid generating a particular waste. Several treatment techniques are, however, available to reduce the waste volume and sometimes the toxicity after the waste has been generated.

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[3] A tri-valent chromate that is not defined as RCRA hazardous has been used in some cases.

Post-Generation, Good Housekeeping Practices Including Waste Decontamination

Liquid waste can be concentrated through evaporation, ion-exchange, filtration, precipitation and centrifuging, and distillation. For example, biomedical institutions use these techniques to separate or concentrate their organic liquids (32). Nuclear utilities use them on several waste streams. For example, evaporation systems and ion-exchange resins are used extensively to treat—concentrate and decontaminate—the large volume of liquid wastes generated during a plant's normal operation. Evaporation is used to concentrate radioactive contaminants; the water is boiled off of liquid wastes, leaving behind most of the dissolved and suspended solids. Ion-exchange resins (demineralizers) are used to remove dissolved radionuclides by adsorption processes. Improvements in the use of these techniques in the nuclear power industry can lead to a 75 percent reduction in "liquid" waste volumes (5).

Neutralization is another practice that could be used to better manage some liquid wastes. Aqueous corrosive liquids, which are mixed LLW due to their corrosiveness, are stored today in tanks. These liquids can be neutralized by raising their pH and then handling them as a purely radioactive waste (20).

One "problem" liquid waste, which is a mixed LLW, is contaminated organic chemicals. In some cases, it is possible to distill the liquid and condense the portion that contains the nonradioactively contaminated chemical. This process would enable the chemical liquid to be reused. Nonetheless, the waste volume would be reduced, not eliminated. The residue would still be a mixed waste. (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

A second problem liquid waste is used oil. Some States consider this waste a mixed LLW, but the EPA is currently deciding whether or not waste oil should be a RCRA-listed hazardous waste.[4] If waste oil is determined to be hazardous, mixed LLW volumes will increase dramatically.

Some generators are filtrating their waste oil, a procedure that removes particulate radioactive contamination. This practice has worked sufficiently well for some generators to allow the "clean" oil to be released to oil recyclers (20). The used filters are disposed of as nonhazardous radioactive waste. Some generators, however, have not been able to filter their waste oil adequately to separate the radioactive constituent from the hazardous constituent. (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

A third problem liquid/wet waste, which is a mixed LLW, is CFC solvents and their concentrates. As mentioned above, CFCs used to dry clean contaminated clothing can be substituted with water-based laundry systems. Nonetheless, problem CFCs are those stored from past dry cleaning services and those generated now or from future cleaning of contaminated tools and equipment. The concentrates can be distilled and heated, thereby reducing the CFC concentration in the waste. Then the recovered CFC solvent can be reused. The residue, however, remains a mixed LLW unless it can be delisted by EPA or found to be a "below regulatory concern" (BRC) waste—waste "not subject to regulatory control to assure adequate protection of the public health and safety because of its radioactive content."[5]

For solid waste, sorting can greatly reduce waste volumes. Sorting nonradioactive from radioactive wastes as well as sorting wastes into different categories (e.g., combustible, recyclable, compactible) are important steps in reducing waste volumes. These sorting techniques are well suited for lightly contaminated dry solid materials such as paper, glass, plastics, metals, rags, and wood. These techniques, in fact, have been argued to achieve the highest overall reduction in waste volumes (32). For example, onsite, semi-automated waste sorting programs can reduce by 40 percent the volume of radioactive dry waste generated by a nuclear power plant (22).

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[4] EPA expects to make this determination in late 1989.

[5] The Nuclear Regulatory Commission (NRC) developed a BRC rule for specific radionuclides in animal carcasses and scintillation fluids in 1981 (10 CFR Part 20.306). This regulation states that these wastes containing tritium and carbon-14 in concentrations less than 0.05 microcuries per gram can be disposed of without regard to their radioactivity. This regulation enables such wastes that also contain hazardous constituents to be incinerated (see section below on "Incineration"). NRC is now evaluating BRC limits for more general cases. EPA has a draft LLW standard which includes limits for BRC. The proposed limits by these agencies are in conflict and this conflict will have to be resolved. Refer to ch. 3 for more detail on the BRC rule. See also 51 Federal Register 168, Aug. 29, 1986; and T. Johnson, "Below Regulatory Concern Wastes—Identification and Implications for Mixed Waste Management," *Proceedings of U.S. Environmental Protection Agency Mixed Waste Workshop*, Denver, CO, July 19-20, 1988.

A number of relatively inexpensive techniques can be used to decontaminate radioactive materials so that they can be reused, reclaimed, or disposed of as nonradioactive waste. A variety of cleaning techniques, including sand blasting, high-pressure steam, acid baths, and electrochemical polishing, can be used to remove surface contamination from metal equipment and tools (e.g., condensers, turbine blades, and scaffolding) that would otherwise be shipped for disposal (27).

A centralized waste processing facility—Quadrex Corp.—for example, cleaned about 6,000 pounds of metal scaffolding over the last several years. In 1987, Quadrex processed approximately 200,000 cubic feet (2 million pounds) of metallic LLW at its facility. Over 90 percent (180,000 cubic feet) of this waste material was cleaned to recover its scrap metal value or so that it could be reused.[6] One estimate places the amount of potentially recyclable metallic LLW at about 540,000 cubic feet per year, roughly 2.5 times the current national recovery rate (14).

Practices are also available to reduce and potentially eliminate lead—the one problem solid waste that is a mixed LLW. In some cases, contaminated lead shielding is cleaned by wiping and rinsing. In other cases, a high-pressure water and chemical hose is used to decontaminate the surface. Chemicals by themselves have also been used to remove contamination. These techniques allow 95 percent of the lead processed to be released as nonradioactive material (20). Lead decontamination solutions can be solidified to pass EPA leachability tests. The solids are then no longer defined as hazardous waste and can be disposed of at a currently operating LLW disposal site (20).

An additional technique for decontaminating lead is separation. If the surface of a particular lead shield is fairly contaminated and the above techniques cannot remove the contamination, it may be possible to physically separate (cutting or scrapping) the surface of the shield so that most of the lead can be released as nonradioactive.

Finally, if surface contamination cannot be removed by the above practices, lead can be smelted so that the contamination is distributed homogeneously throughout the metal matrix. Once EPA and NRC agree on limits for BRC, it may be possible to reduce the radioactivity to such a degree that the lead is found to be BRC. At the Department of Energy (DOE) National Engineering Laboratory's Waste Experimental Reduction Facility (WERF) in Idaho, this smelting technique is used. In the Federal Republic of Germany, ingots of these melts are used as shielding materials at nuclear power plants.

The BRC rule could also have a significant impact on reducing LLW volumes in general. The Electric Power Research Institute estimates that the nuclear utility industry alone could see a 30 to 40 percent drop in its volumes from 1988 figures.[7]

Storing Radioactive Material for Decay

A large fraction of the radioactive material generated by medical and biomedical research institutions is composed of relatively short-lived radionuclides. By storing these LLW materials for time periods equivalent to 10 to 20 half-lives, the radioactivity can decline to background levels. This waste is essentially nonradioactive in that it can be regulated without regard to its radioactivity.[8] After storing such radioactive waste for the necessary period, it can be disposed of with other solid wastes in a landfill, or it can be released into the sewer system in regulated amounts (see 10 CFR Part 20.303).

Most of the radionuclides used in nuclear medicine have half-lives that are less than 7 days (26). Storage for decay is typically done by collecting all the waste generated within specific periods, usually

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[6] Norman Dudey, Quadrex Corp., personal communication, Dec. 15, 1988.

[7] Patricia Robinson, LLW Program, Electric Power Research Institute, presentation made at *The Fifth Annual Decisionmakers' Forum—LLW Management: The Available Options & Costs*, Wild Dunes, SC, June 6-8, 1989.

[8] The actual storage time needed for a radionuclide to be at or below its concentration in the natural environment (background level) depends on its concentration in the waste and its half-life.

30-day intervals, and then storing the waste as one unit. Each unit of waste is segregated by radionuclides. Either shielded or unshielded storage containers are used, depending on the waste. The waste is stored until it is no longer considered radioactive.

Without storage-for-decay programs, the combustible dry waste and animal carcasses generated by medical institutions could not be incinerated, and approximately 30 percent of the aqueous waste could not be emptied into the sewer. A typical biomedical research institution can reduce the volume of LLW requiring disposal by 30 to 40 percent through an in-house storage-for-decay program (32).

Storage-for-decay programs may also help eliminate certain categories of potential mixed LLW. For used scintillation liquids, it may be possible to use less radioactive material or radionuclides that have very short (measured in minutes) decay periods. These modifications may be possible by using detection equipment with increased sensitivity. The liquid waste in this example could be considered no longer radioactive and, thereby, handled as only a hazardous waste (32).

Two problems arise with some of these storage-for-decay programs. First, a RCRA permit for short-lived radionuclides is required for 90-day or longer storage.[9] Furthermore, even with such a permit, RCRA land disposal restricted waste can only be stored if storage is for the sole purpose of accumulating sufficient quantities to facilitate proper recovery, treatment, or disposal (40 CFR Part 268.50). Since no treatment facilities are available that meet the RCRA treatment standard and no disposal facilities are available, it is unlikely that storage would be allowed. The storage prohibition does not apply, however, if one of the exemptions to the RCRA land disposal restrictions are in effect.[10] Some procedures generate LLW, as well as mixed LLW, with longer-lived radionuclides. For example, iodine-125, which has a half-life of 60 days, should be stored for about 2 years before it can be disposed of without regard to its radioactivity. If this iodine were mixed LLW, storage would not be allowed according to EPA. This prohibition is a particular problem for some mixed LLW when no alternative minimization or treatment technique can alter it so that it is either solely radioactive or solely hazardous. For mixed LLW containing radionuclides that must be stored longer than 2 years before they decay to such low levels that they can be disposed, generators have no choice but to either stop the practice responsible for generating the waste, which can often mean going out of business, or illegally store the waste.

Most mixed LLW generators have not yet submitted their RCRA Part A permits for storage, and EPA has not begun to enforce its storage regulations. Once enforcement begins, generators will have problems handling these mixed waste streams. (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

Second, some storage-for-decay programs lack quality control over long-term storage. Degradation of waste packages, for example, can result in excessive radiation exposure to workers.

Compaction and Shredding Techniques

The volume of dry LLW (i.e., trash) can be substantially reduced before disposal by mechanical compaction and shredding techniques. For example, from 50 to 65 percent of the dry waste generated by nuclear power plants can be compacted to reduce the disposal volume (3).

In general, compactors are simple to operate and relatively inexpensive; an exception is supercompactors which are more complex and cost between $1 million and $5 million to purchase and install. Compactors must be equipped with air filtration

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[9] Generators that qualify as conditionally exempt small quantity generators (they generate less than 100 kilograms (kg) (220 pounds) of hazardous waste per month) do not need storage permits as long as the total amount of all hazardous waste (including mixed LLW) does not exceed 1,000 kg (2,200 pounds). Generators that produce between 100 and 1,000 kg (220 to 2,200 pounds) of hazardous waste per month may store this waste onsite for up to 180 days without a storage permit, provided that the total amount of all hazardous waste (including mixed LLW) accumulated onsite does not exceed 6,000 kg (13,200 pounds). The 180-day limit can be extended to 270 days if the distance the waste must be transported for offsite treatment, storage, or disposal is 200 miles or more (40 CFR Part 262).

[10] Existing provisions for exemptions under the RCRA land disposal restrictions include a 2-year national capacity variance, an approved no-migration petition, or an approved case-by-case extension. Case-by-case extensions are only allowed if the applicant can demonstrate that he/she has entered into a binding contract with a treatment facility operator/developer that will construct or otherwise provide alternative treatment, recovery, or disposal capacity for the entire waste stream after the extension expires (1). See ch. 3 for a more detailed discussion of storage prohibitions and their relationship to treatment standards and land ban restrictions.

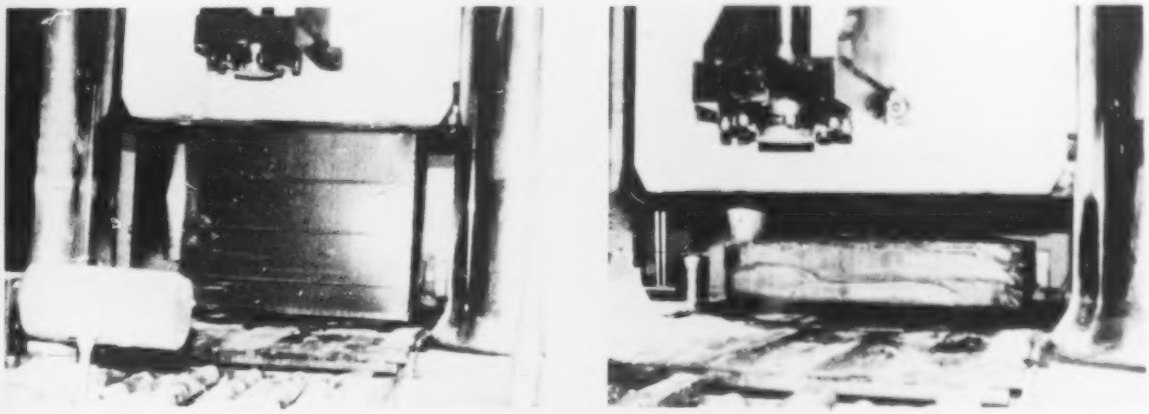

Photo credit: Scientific Ecology Group

Before and after photos of box compaction using a 5,000-ton supercompactor

units to control the release of airborne contaminants and to minimize worker exposure. An added advantage of compactors is that the processed waste is of uniform geometry, which facilitates handling and packaging and reduces the space needed for interim onsite storage (21).

Supercompactors in use today are either stationary or mobile units capable of producing a force of 1,000 tons or greater. These units can crush containers of waste (55-gallon drums or boxes) into "hockey pucks" in a manner of minutes (11). These high-tonnage systems are capable of handling a larger fraction of the so-called noncompactible wastes, which represent a large part of a nuclear power plants' waste volume (8).

Using a 5,000-ton device, centralized waste processing companies like the Scientific Ecology Group, Inc. (SEG), a waste processing company in Tennessee, can supercompact the dry wastes from a wide variety of generators. In 1988, SEG processed more than 800,000 cubic feet of waste, an increase of 40 percent from 1987. Only 167,000 cubic feet of this waste—a volume reduction of almost 80 percent—was left to be shipped for disposal.[11] Before the waste is compacted, materials like wood and metal that are nonradioactive or that can be decontaminated are separated from the waste stream. Liquids that are released in the compaction process are solidified in cement and placed with the compacted waste.

Size reduction devices such as shredders can also be used to reduce waste volumes (27). Shredders tear, rip, shatter, and/or crush waste materials into smaller sizes. By using supercompactors and/or shredders, it is possible to achieve up to a seven-fold-or about an 85 percent volume reduction (27). Shredders can also provide a more uniform feed material for incinerators.

Incineration

Incineration is one of the most efficient ways of reducing waste volumes. The techniques discussed below have mainly been used to treat municipal solid waste, but they could be used to treat low-radioactivity, combustible liquid and solid dry LLW. The major differences in applying this technology to LLW involve shielding requirements, the use of high-efficiency filters, and methods of ash disposal (27). Incineration can reduce waste volumes by a ratio of at least 25:1 (or 96 percent). Although this experience indicates that it is rather difficult to design a universal incinerator capable of treating all the various waste types at equal efficiency and performance (7). With respect to some mixed LLW, incineration can convert the waste into carbon dioxide and radioactive ash (7). Incineration is likely to be inappropriate for treating LLW, including mixed LLW, that contains radionuclides that cannot be trapped by an off-gas system.

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[11] Bud Arrowsmith, Scientific Ecology Group, Inc., personal communication, Oct. 19, 1988.

Types of Incinerators

Three major types of incinerators are currently used worldwide to reduce LLW volumes: 1) rotary kilns, 2) controlled-air incinerators, and 3) fluidized-bed incinerators.

A typical incinerator facility consists of a waste sorting system, a waste feeding mechanism, a main combustion chamber, often an afterburner, an elaborate off-gas cleaning system, an ash collection and removal system, a waste conditioning unit, and instrumentation to monitor critical operating parameters to ensure that health and safety-related limits are met. Incinerators differ in their design based on the amount of air used, the special characteristics of the combustion chamber, and the form of the incineration residue.

In a rotary kiln, waste is decomposed (oxidized) by burning in a slowly rotating, refractory-lined combustion chamber mounted at a slight incline so waste gradually gravitates toward the ash discharge point. This chamber contains more oxygen than necessary to completely oxidize the waste. Liquid injection units are often coupled with this design for liquid wastes. To ensure complete combustion, a secondary combustion chamber (afterburner) is often used to increase the time that wastes are subjected to high temperatures. A relatively large amount of ash and particulates can be produced by this type of incinerator (24).

In a controlled-air incinerator, waste is fed onto a platform in the bottom of a combustion chamber. This primary chamber as well as the secondary combustion chamber can be operated under either starved-air (pyrolytic) or excess-air conditions. The conditions chosen depend on the waste type. With LLW incinerators, it is common to operate the primary chamber under pyrolytic conditions because the amount of fly ash produced is greatly reduced. Liquid injectors can also be attached to this chamber to destroy liquid wastes. Particles of incomplete combustion are then fed into a secondary high-combustion chamber that is oxygen enriched. The advantage of this design is that less fly ash is produced, therefore less radioactive dust is carried out with escaping combustion gases (24, 7). Nonetheless, an elaborate off-gas system accompanies this design (see following discussion on air pollution control technologies).

A fluidized-bed incinerator uses a layer of small particles (e.g., sand, limestone) suspended in an upward flowing stream of air like a fluid (hence, the name) to help burn highly viscous liquids and sludges not easily burned by other incinerators (24). The flowing particles help the mixing and the combustion efficiency. This design can also remove acid gases (27). A disadvantage of this design is that combustion gases can contain high levels of particulates (24).

Two other technologies—wet air oxidation and supercritical water oxidation—are similar to incineration but involve water. Wet-air oxidation is used by hazardous waste facilities to oxidize organic contaminants in water (24). Low temperatures can be used with this technology because the water modifies the oxidation reactions, and the reactor vessel is maintained at a pressure high enough to prevent excessive evaporation. Supercritical water oxidization is similar, but temperature and pressure are higher than with the wet-air oxidation process. By raising primarily pressure and to some degree temperature, the rate and efficiency of thermal oxidation can be enhanced (24). Neither of these water-based thermal oxidation processes is commercially available. The DOE Los Alamos Laboratory has an on-going research project under its Hazardous Waste Remedial Action Program (HAZWRAP) using supercritical water oxidation. These technologies, particularly supercritical water oxidation, may hold promise for destroying organic chemicals containing radionuclides like tritium and carbon-14, which are nearly impossible to trap in conventional off-gas incinerator systems.[12] One European report noted a trend toward using special incineration systems for less voluminous wastes with special characteristics (e.g., solvents) and/or special contaminants (7).

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[12] This consensus was reached at the *Workshop on Supercritical Fluid Processing of High Risk Wastes*, held at the Los Alamos National Laboratory, Los Alamos, New Mexico, Aug. 1-2, 1989.

Air Pollution Control Technologies

Air pollution technologies are used to control the emission of gases and radioactive particulates. The amount of radioactivity released into the atmosphere from an incinerator depends in part on the volatility of a particular radionuclide during the combustion process. As mentioned above, it is very difficult to prevent the release of volatile radionuclides, like carbon-14, tritium, and iodine-131, with current technologies.

A small amount of the waste's total radioactivity is transported in particulate matter by combustion gases leaving the chamber, while most radionuclides are trapped in the ash or slag (melted ash) that settles to the bottom of the combustion chamber. The concentration of radioactivity in the fly ash can be even higher if the volume of dust particles produced is limited. A combination of technologies is used to remove these radioactive particles from the combustion gases: fabric baghouses, high-temperature ceramic filters, electrostatic precipitators, and high-efficiency particulate air (HEPA) filters. For example, in some systems, gases pass through the baghouses, and fly ash is collected on the outer surface of the bags. On a periodic basis, the fly ash is driven off of the bags by injecting a burst of compressed air through a venturi in the top of each bag. This burst of air knocks the fly ash off the bags and into a hopper at the bottom of each baghouse. This fly ash is collected, processed (e.g., solidified using a cement waste form), and disposed of. After gases pass through the baghouses, they are sent through HEPA filters designed to remove over 99 percent of particles larger than 0.3 microns (2).

Operating Experience

Incineration has been used extensively in Europe (e.g., Federal Republic of Germany, Sweden) and in Japan since the early 1970s to treat commercial LLW generated by hospitals, nuclear power plants, and industry. In Sweden, more than 600,000 cubic feet of dry active waste were incinerated between 1976 and 1983 at a central LLW processing facility (16). During this period, less than 2 percent of the maximum permissible amount of beta and gamma radionuclides were released into the atmosphere via the stack gases. A strict quality control program—to ensure that a waste package's manifest accurately reflects the waste's contents—has been found to be critical in minimizing emissions (4).

In the United States, no commercial incinerator is licensed to treat LLW or mixed LLW. About 100 individual licensees have incinerators for certain combustible wastes generated at their sites, but incinerators for commercial use are not available. In contrast, the DOE has incinerators within its weapons complex sites that can treat both LLW and mixed LLW, and these wastes are shipped between weapon sites for treatment. The WERF incinerator at the Idaho National Engineering Laboratory, for example, routinely burns LLW and on a smaller scale burns liquid mixed LLW. The incinerator is currently operating under RCRA interim status (27). The DOE Oak Ridge National Laboratory is planning to open in February 1990 its Toxic Substance and Control Act (TSCA) incinerator, which will be permitted to burn mixed LLW. Both of these incinerators burn or will burn wastes from other DOE sites.

The only U.S. commercial facility that is scheduled to be available in November 1989 is a controlled-air incinerator operated by SEG in Oak Ridge, TN. The incinerator will be capable of burning 800 to 1600 pounds of dry solid waste per hour. Included in the design is a system to handle liquid wastes and a glass furnace to stabilize final ash products. This incinerator will be permitted to burn only non-mixed LLW

Incineration of Mixed LLW

In Europe, mixed LLW is defined simply as radioactive waste. Operators of treatment and disposal facilities, therefore, do not have to obtain special permits or meet special standards for this waste.

In the United States, in contrast, there are incinerators to treat hazardous waste, but not commercial mixed LLW. Although SEG has the technical capability to treat mixed LLW at its soon-to-be operating incinerator, the company has not filed for the necessary permits.

The bulk of mixed LLW—scintillation fluids—is incinerated because it is not regulated as a mixed LLW. From a regulatory standpoint, most of these fluids are below the established limits set by the Nuclear Regulatory Commission to be BRC and, therefore, are regulated for their nonradioactive characteristics. Most of these BRC fluids are shipped to one company in Florida—Quadrex Corp.—that burns them to recover their energy value. The fluids are an energy supplement to the fuel that runs an incinerator. The heat from the incinerator, in turn, is used to make cement blocks. Because the incinerator is an energy recovery system, it does not require a RCRA permit. This situation will likely change due to the amendments EPA is currently drafting;[13] EPA will likely determine that energy recovery facilities, like the incinerator Quadrex uses, will require a RCRA permit. Quadrex plans to use an incinerator that has a RCRA permit, if this determination is made.

As with the BRC scintillation fluids, waste oil has typically been burned as a fuel substitute because usually it is only slightly contaminated. This oil is produced in large quantities by nuclear utilities and some industrial generators. Many generators incinerate their waste oil onsite, while others ship it to a waste processor. SEG, for example, treats approximately 30,000 gallons of waste oil annually.[14]

The status of waste oil may soon change. EPA is reevaluating whether waste oil should be listed as a hazardous waste and is expected to make a decision in late 1989. If waste oil is found to be hazardous, then generators/waste processors will need a RCRA permit to incinerate their waste oil. All States will have to amend their regulations to include this definition. If waste oil does become defined as a RCRA-listed hazardous waste, the volume of mixed LLW will rise dramatically. Without a RCRA-permitted incinerator available, the waste oil that cannot be successfully filtered will have to be stored. This volume would only be reduced if this waste falls below the yet-to-be-finalized BRC limits.

Another type of mixed LLW for which no incinerator is available is organic chemical waste. Several technologies (e.g., supercritical water oxidation) have been identified in the laboratory as being able to possibly treat this waste effectively but they have not been developed nor tested commercially (25). (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

Waste Stabilization

Stabilization techniques are used to fix the constituents of LLW, including mixed LLW, in a solid form that is inert, that has low exchange or release rates in water, and that can be safely transported or stored. The solid form in which a waste is fixed is called the waste form. For example, incinerator ash can be stabilized in a cement-based waste form that fixes the ash and retards the migration of radionuclides in the waste. Several different stabilization media are available. Finally, a waste packaging container designed for a particular waste form is critical to ensuring long-term stabilization of the waste and, in turn, the protection of public health and safety and the environment during storage, shipment, and disposal.

Technical Requirements

LLW must be stabilized based on the following requirements (10 CFR Part 61) (28, 30):

Minimum Requirements for All Classes of LLW

1. Minimum packaging requirements must be met (e.g., no cardboard boxes are allowed), but the waste does not have to be solidified or placed in a special container.[15]
2. Liquids are to be solidified or packaged in twice the volume of liquid absorbent. (The use of absorbents is, however, prohibited in some Agreement States.)
3. No more than 1 percent of a solid waste's volume shall contain liquids.
4. The waste must not be explosive, pyrophoric, capable of generating harmful gases, toxic, or infectious.
5. Waste should not generate gas pressure greater than 1.5 atmospheres at 20 °C and must contain less than 100 curies per container.

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[13] EPA issued a supplemental notice on October 26, 1989, that requires energy recovery facilities to be permitted. This supplemental notice is effectively a reproposal of a proposed rule issued on May 6, 1987. EPA plans to issue a final rule in early 1991.

[14] Arrowsmith, op. cit., footnote 11.

[15] In Washington and South Carolina, certain Class A wastes (those having radionuclides with half-lives greater than 5 years in concentrations greater than 1 microcurie per cubic centimeter) must also be stabilized (27).

6. Waste containing hazardous, biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard from the nonradiological materials.
7. A process control (testing) program must be used to ensure that the waste product is of consistent quality.

Additional Requirements for Class B and C Waste

1. The waste form must be structurally stable.
2. Liquid waste must be converted into a form that contains no more than 1 percent of the waste's volume, when the waste is in a disposal container designed to ensure stability, or 0.5 percent of the waste's volume, when the waste is processed to a stable form.
3. Void spaces within the waste and between the waste and its package must be reduced to the extent practicable.
4. The gross physical properties of the waste form must be retained for at least 300 years under all disposal conditions (e.g., irradiation, high compressive loads, exposure to moisture, and biological degradation).
5. Instead of using solidification agents (e.g., cement) to fix the waste, Class B and Class C waste may be stabilized in a suitable high-integrity container (HIC). When a HIC is used, the maximum amount of free liquid cannot exceed 1 percent of the waste volume.
6. Class C waste must be disposed of so that the top of the waste is at least 15 feet below the surface or disposed of with intruder barriers designed to protect against inadvertent intrusion for at least 500 years.

Waste Form Types

Typical stabilization techniques include solidifying wastes using lime-based cements, bitumen (asphalt), and synthetic polymers (e.g., vinyl ester-styrene and urea-formaldehyde). Wastes are also stabilized by certain waste packages. HICs composed of organic polymers like polyethylene and various stainless steel alloys are used to stabilize waste.

In the United States, cement mixtures have been preferred as stabilizing materials, while in Europe bitumen has been used for over 20 years to stabilize radioactive wastes.

In cement-based waste forms, waste solidification occurs by a complex chemical hydration reaction (i.e., water and lime are added to produce a calcium oxide). The advantages of this waste form are that:

- it effectively stabilizes most LLW,
- it has a high structural strength,
- it is inexpensive to produce and easy to use, and
- it exhibits a low leachability for most radionuclides.

The disadvantages of cement-based waste forms are that:

- it, unlike bitumen, increases a waste's volume by 10 to 30 percent,
- it is difficult, though not impossible, to use in solidifying mixed LLW composed of untreated detergent, oils, and other organic liquids because these substances interfere with the hydration process (27), and
- it may also be incompatible with mixed LLW composed of metallic salts.

In a recent NRC Notice (31), other disadvantages with cement-based waste forms were listed. These include:

- its failure to solidify completely,
- swelling and bulging of liners, and
- disintegration over relatively short periods following solidification.

In particular, bead resin, decontamination solutions, borates, sulfates, and oils were listed as wastes that had problems when solidified using a cement. The NRC announced at one of its workshops that several cases of full-scale and lab-scale waste forms have had these problems (18). Likewise, the Idaho National Energy Laboratory reported that it had similar problems in using cement-solidified waste forms and that the waste formed cracks during leaching (18).

In the United States, cement is often combined with numerous natural and synthetic sorbable materials to stabilize waste. This combination makes it easier to stabilize some organic mixed LLW. However, waste forms that depend on sorption techniques are, by themselves, inadequate stabilizing agents due to the reversible nature of most sorption processes.

Bitumen systems are considered to be both waste stabilization and volume reduction technologies because the heat required to melt the mixture assists in evaporating any liquid wastes (27). The hot bitumen coats the waste particles, thus encapsulating the waste in a solid matrix that is impermeable to water and structurally stable once it cools. Bitumen can be used to stabilize almost all LLW materials with the possible exception of certain mixed LLW, such as those containing liquid organic chemicals (e.g., oil). The major advantages of using bitumen are:

- its good leach resistance characteristics,
- the low operating costs of producing it,
- the ease of handling it, and
- its high waste loading capacity.

The major disadvantages of using bitumen are:

- its relatively low ignition temperature (i.e., it is flammable),
- its instability at high temperatures,
- its relatively low (in comparison to cements) structural strength, and
- its susceptibility to biological degradation (27).

Polymers, in contrast, solidify wastes by a chemical reaction process called polymerization. Advantages of this waste form are that:

- wastes are very resistant to chemical leaching, and
- they exhibit high compressive strengths.

The major disadvantages of using this waste form are:

- the high material costs,
- the complexity of the mixing process, and
- the fire and explosive hazard posed by some of the chemical ingredients of the polymer.

Table 5-2 summarizes the advantages and disadvantages of these three waste forms. Cement has many advantages, but its quality is inconsistent and it produces higher waste volumes. Bitumen exhibits the opposite characteristics, in that its quality is consistent and it reduces waste volumes; however, it is not as structurally strong as cement. Neither cement nor bitumen can adequately stabilize some mixed LLW, particularly organic chemical waste. In comparison to either cement or bitumen, polymer waste forms appear to have no major advantage. A combination of these waste forms may be most appropriate for some mixed LLW. NRC has an active research program in this area to improve waste form reliability.

Table 5-2—A Critique of Waste Forms

Characteristic	Cement	Bitumen	Polymer
Leach resistant	Y	Y	Y
High structural strength	Y	N	Y
Not flammable nor ignitable	Y	N	N
Easy to use	Y	Y	N
Consistent quality	N	Y	U
Appropriate for organic chemical mixed wastes	N	N	U
Reduces waste volume	N	Y	I
Inexpensive	Y	Y	N

KEY: Y = yes
N = no
U = unknown
I = indifferent

SOURCE: Office of Technology Assessment, 1989.

Waste Packaging Materials

A variety of different packaging materials are used for LLW containers. Wooden boxes are used at some disposal sites (in arid regions) for Class A waste. Steel drums and steel boxes are also used for Class A waste. HICs made from a variety of materials (e.g., polyethylene, steel-reinforced concrete, and stainless steel) are used for Class B and C waste. As noted, these packaging materials are designed to retain their physical and chemical integrity for at least 300 years (30).

In general, polyethylene is a highly corrosion-resistant material, but its long-term structural integrity is of concern. Studies conducted at the Brookhaven National Laboratory found that polyethylene containers may become brittle, crack, and rupture when exposed to certain chemical contaminants (e.g., organic liquids such as oils) and to high doses of radiation (23). The NRC allows the use of these containers for disposal but only if the required structural stability is provided by other packaging materials or engineered structures (17). Containers made of various steel alloys are also used to stabilize LLW and some mixed LLW because of their high structural strength and their ability to resist corrosion (though not to the same degree as polyethylene).

A number of containers on the market use a combination of several materials to form a container with improved stability characteristics (27). For example, a polyethylene container within an inner steel or concrete container has been used. Polymer-impregnated cements have also been used to reduce the leaching of some radionuclides (e.g., cesium and strontium) (19). As with waste forms, more research is needed on packaging materials that may be appropriate for various mixed LLWs.

Long-Term Stability Predictions

It is important to be able to predict how the materials used to stabilize LLW and mixed LLW will behave in a disposal environment over the long term. The most common prediction methods are based on the results from short-term laboratory tests. Leachability, due to groundwater, is one of the most important factors in determining the long-term stability of a waste form or container. Leaching tests measure the ability of a particular waste form or container to retard the release of specific radionuclides or hazardous chemicals. These tests are conducted by placing a sample of the stabilized material in water and then measuring the release rates (of individual chemical species) over a period of about 90 days.

Experimentally determined leaching rate predictions must be viewed with caution for several reasons:

- the tests are based on short-term studies (often 90 days or less);
- the experimental conditions are generally not representative of the variety of geochemical conditions encountered in a disposal environment;[16] and
- very little to no quantitative information exists on the long-term stability of containment materials under disposal conditions.

With respect to the third reason, the only long-term database available is for concrete. Two-thousand-year-old concrete structures (e.g., bridges, aqueducts, and harbors) from the Roman era are still in existence. Studies of these structures show that the concrete has retained most of its structural strength, but often has undergone extensive chemical transformation as a result of exposure to ambient environmental conditions (12). Many examples can also be cited where modern concretes have performed satisfactorily for at least 100 years. It is difficult to be certain, however, that concrete will remain structurally stable and resistant to leaching for much more than a few hundred years (12).

TYPES OF MIXED LLW FOR WHICH NO MINIMIZATION OR TREATMENT TECHNIQUES ARE CURRENTLY AVAILABLE

A major problem for mixed LLW generators is that no commercial facility is available to treat their wastes. According to EPA regulations, a particular treatment standard must be met for a particular hazardous waste before it can be disposed. The standard may be expressed as a specified technology (e.g., incineration), as a total concentration in the waste, or as a concentration in the waste extract (i.e., by using a leaching test called the Toxicity Characteristic Leaching Procedure or TCLP) (1). In all cases, these treatment standards are based on the performance of the best demonstrated available technology (BDAT).

EPA treatment standards for solvents, dioxins, and the hazardous constituents that fall on the California List[17] are in effect and apply to mixed LLW that contains these hazardous constituents. Therefore, mixed LLW generators are required to treat these wastes accordingly. **There are three types of mixed LLW identified for which treatment is necessary, but a treatment facility is unavailable.**

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[16] Because of the variety of possible geochemical conditions at a site, it is difficult to devise a standardized leaching test that represents the potential mobility of radioactive (or chemical) contaminants.

[17] The California List includes free cyanides, corrosives, hazardous waste mixed with polychlorinated biphenyls (PCBs), and certain metals (i.e., arsenic, cadmium, chromium, lead, mercury, nickel, thallium, and selenium) (RCRA sections 3004[d][1], [d][2], 42 U.S.C. 6924 [d][1], [d][2]). For treatment standards for these wastes, see EPA's final rule—52 Federal Register 25760, July 8, 1987.

First, **organic chemicals**, in some cases, can be distilled and the nonradioactively contaminated chemical can be concentrated for re-use. Nonetheless, the residue is still a mixed LLW. For the most part, organic chemical mixed LLWs fall into the solvent category, and the BDAT for solvents is incineration. No commercial incinerator, however, is available to treat organic chemical mixed LLW. Furthermore, as mentioned, some organic chemicals contain high concentrations of radionuclides (e.g., tritium and carbon-14) that would escape through a conventional off-gas filtering system if incinerated. Newly designed incinerators or completely new techniques (e.g., some water-based thermal oxidation process, like supercritical water oxidation, or some new stabilization technique) may be needed to treat these wastes.

Second, **waste oil** may be a problem with respect to treatment. If EPA decides that waste oil is a RCRA-listed hazardous waste, the overall volume of mixed LLW will dramatically increase. All generators of mixed LLW oil will have to meet the established treatment standard, and the BDAT to meet this standard will likely be incineration. Based on comments from some generators, it appears unlikely that filtration will successfully work in all cases for separating radioactive particulates from oil. Therefore, incineration will be required. As with organic chemicals, no commercial mixed LLW incinerator is available.

Third, **chlorofluorocarbons** (CFCs) used in dry cleaning of clothing may also be a problem with respect to treatment. Even though many generators have shifted to water-based laundry systems, CFC solutions from past practices are in storage. Moreover, CFC solutions and sludges from decontaminating tools and equipment are in storage and will continue to be generated. As with organic chemicals, these solutions can be distilled and the nonradioactively contaminated solution can be concentrated for re-use. Nonetheless, the residue is still a mixed LLW. Because the concentration of radioactivity in these solutions is generally very low, generators hope to have them delisted or found to be BRC once the standard is finalized. The BDAT for CFCs is incineration, and, until a delisting petition is granted or the BRC standard is finalized, generators should be incinerating them. However, no commercial mixed LLW incinerator is available.

All generators that have land-disposal-restricted mixed LLW for which no treatment technique is available have no options but either to stop the practice that generates the waste, which in many cases means going out of business, or to store their waste. Storage is, however, only allowed for a period long enough to accumulate enough volume to further manage the waste. With no treatment or disposal capacity available, it is unlikely that the accumulation argument can be used by generators. They can apply for a case-by-case extension to a land disposal restriction for up to 2 years, during which time the storage prohibition does not apply. However, to receive the extension, the generator must be able to demonstrate that a good-faith effort has been made to locate and contract with facilities nationwide to manage its waste, and that a binding contract has been entered into with a treatment operator/developer that will construct or otherwise provide alternative treatment, recovery, or disposal capacity for the waste. The contract must ensure that this capacity will be available at the end of the extension period.

It will unlikely be possible to provide a treatment technique for some mixed LLW types in this timeframe. In particular, developing techniques and making them available for some organic chemical solvents with long-lived radionuclides or high concentrations of radionuclides may be difficult. If storage of such wastes extends significantly, excessive radiation exposures to workers could result if adequate storage conditions are not maintained and waste packages degrade (20).

Another problem with mixed LLW management is that EPA has not completed establishing treatment standards for all hazardous wastes. Nonetheless, it appears that treatment standards have been established for the majority of commercial mixed LLWs (e.g., organic solvents) identified that cannot be treated so that they are no longer a mixed LLW. A comprehensive national survey, however, has not been conducted to determine all the possible mixed LLWs that are being generated. A survey may uncover some types of unalterable mixed LLW for which treatment standards are not available.

A survey could also serve other needs. States would have a database to draw on to know which institutions/facilities are generating mixed LLW and to know the waste types and their volumes. This information would help States in their regulation of mixed LLW as well as in their development of a mixed LLW disposal facility. Furthermore, a mixed LLW survey could provide the treatment industry with the necessary information to develop treatment facilities to meet RCRA standards. This industry has often argued that it is leery of developing treatment facilities (e.g., incinerators) because it lacks this information. A survey could meet these needs.

A BRC standard could also help resolve some of the mixed LLW management problems. As mentioned above, by using a BRC standard, generators may be able to dispose of CFC residue and lead as hazardous waste, thereby omitting these two waste types from the mixed LLW category. Depending on the concentration of radioactivity in waste oil, it too might be removed from the mixed LLW list.[18] **Theoretically, this would leave one problem mixed LLW—organic chemicals containing high concentrations of radionuclides that cannot be trapped in an incinerator off-gas system. A new treatment or stabilization technique may be needed for these wastes.**

THE FUTURE FOR WASTE MINIMIZATION AND TREATMENT TECHNIQUES

Future Disposal Volumes

In reaction to the volume restrictions (i.e., disposal allocations established in the Low-Level Radioactive Policy Amendments Act of 1985[19]) at existing disposal sites, the slow progress in siting new disposal facilities, and increasing disposal costs, LLW generators have been reducing the volumes of waste they ship for disposal. Between 1980 and 1988, these factors were responsible for a 55 percent volume reduction in commercial LLW shipped for disposal (see ch. 4). From 1984 to 1987, the nuclear power industry reduced its waste volume by about 42 percent, while at the same time the industry built 20 new reactors (6). Since the late 1970s, institutional generators have used a variety of the technologies discussed in this chapter to reduce their LLW volumes shipped for disposal by 94 percent (32).

Waste minimization techniques can be used more extensively to avoid generating some LLWs by improving technology transfer between generator communities. Once the waste has been generated, incineration and decontamination techniques appear to have the greatest potential for reducing future LLW volumes.

Interstate LLW Management Services

The cost of disposing of LLW will almost certainly continue to rise in the future, due to the increased costs of constructing the newer engineered disposal facilities (see ch. 6). Higher disposal costs alone, however, may not drive waste volumes down to the maximum extent practicable, particularly if compacts decide to prohibit interstate processing of LLW. It probably will not be economically viable for States and compacts with a small waste volume to develop their own incinerators. The capital costs of constructing an incinerator are high, ranging from $7 million to $9 million for a system capable of handling 85,000 pounds of waste per year, while annual operating and maintenance costs are around $500,000 (27). Incinerators have also been proven to be very difficult to site and license. With no access to an incinerator, volumes in these regions will not decrease significantly. It appears that the overall costs and some handling and transportation risks (see below) can be reduced by encouraging interstate processing of wastes.

Mixed LLW Management

The waste minimization and treatment techniques discussed in this chapter will continue to reduce the volume of mixed LLW. **Generators will be pressured even more to maximize their use of these techniques, once EPA enforces its RCRA regulations and requires all generators to obtain a permit for treating and/or storing their mixed LLW.** To avoid dual jurisdiction—to avoid having to obtain a RCRA permit in addition to the NRC or

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[18] By defining a mixed LLW as BRC with respect to its radioactivity, however, does not guarantee that a hazardous waste landfill will accept the waste. The landfill may have stricter requirements in its permit and refuse the waste. In such instances, the waste generator is left with no disposal option at present.

[19] Public Law 99-240, Jan. 15, 1986.

Agreement State license they currently have—mixed LLW generators will try to change their practices and not generate mixed LLW or will try to treat all mixed LLW such that it is either solely radioactive or solely hazardous.

The generation of some mixed LLWs is, however, unavoidable. Of primary concern is the storage prohibition that applies to mixed LLW. As a remedy, EPA could decide, in establishing its treatment standards for the final third of hazardous wastes (due to be released in May 1990), that the storage prohibition does not apply to generators of wastes for which no treatment capacity and/or no disposal capacity is available. In other words, storage would be allowed if it is not being used in place of disposal.

An advantage of this approach is that mixed LLW generators would have an intermediate option until treatment capacity and disposal capacity are available. Furthermore, by generators applying for a storage permit, EPA would have a record as to what types and volumes of mixed LLW are being generated. EPA could use the data to better ensure that wastes are not being illegally disposed. The waste treatment industry also could use the data as a marketing tool to develop necessary waste treatment facilities, as it could with data from a national survey.

Generators claim that dual jurisdiction is very burdensome in that they have to meet two separate agencies' requirements, including filling out separate forms that often request the same information. EPA has stated, however, that it will try and "accept, to the extent possible, information already submitted to the NRC when processing a RCRA permit."[20] Likewise, NRC has said that the two agencies will work toward "resolving the difficulties of simultaneous licensing and permitting processes, making the overall process more uniform, and exploring the possibility of using the same application document," but NRC notes that this effort is of low priority compared to joint guidance efforts (13). Even given these intentions, generators are discouraged and anxious about dual jurisdiction because of the lack of progress they have seen the two agencies make toward streamlining the permitting/licensing process for the treatment, storage, and disposal (which is discussed in ch. 6) of mixed LLW.

Dual jurisdiction is likely to be difficult until EPA and NRC agree to joint rulemaking or joint guidance concerning several regulatory issues. In some cases, the two agencies have different approaches and these approaches may be in conflict. Joint rulemaking and/or joint guidance will likely be needed on waste package manifest requirements, waste package sampling and testing, and inspection and enforcement of treatment, storage, and disposal facilities. For sampling, EPA requires a 100-gram specimen. NRC is concerned that this size sample is too large and in conflict with its principle of keeping worker exposure as low as reasonably achievable. EPA headquarters has told its regional offices that, if this conflict does arise, the office should accept smaller samples.[21] In addition to other cases of possible regulatory conflict and overlapping and duplicative regulations (see ch. 1 and ch. 3), the NRC and EPA may find other regulatory areas that will require joint rulemaking and/or joint guidance.

Of all the types of mixed LLW discussed, three types stand out as the most difficult for generators to manage—organic chemicals, waste oil, and CFC residue. Of these three wastes, organic chemicals seem to offer the greatest challenge from a treatment perspective. **If a comprehensive survey of mixed LLW is conducted and/or EPA develops a record of stored mixed LLW by permitting such practices, States would have the information they need to regulate these wastes and to develop disposal capacity. In addition, industry would have a clearer idea of the technology and capacity needed to treat these three wastes.**

Risks of LLW Management

Neither incineration nor decontamination—the two most efficient waste volume reduction techniques—will reduce the total curies generated, because curies cannot be destroyed. Through current incineration techniques, some radionuclides (e.g., tritium and carbon-14) will be released into the atmosphere and some will be fixed in the ash. The total radioactivity emitted from these two pathways will be equivalent to that in the waste prior to incineration. Likewise, the radioactivity extracted during decontamination is equivalent to the radioactivity in the waste prior to decontamination. It is difficult to determine which exposure pathways have the greatest risk to humans and the environment. Nonetheless, aside from the limited radioactivity that escapes via stack gases, all radioactivity disposed of under either scenario (disposal without incineration or decontamination versus disposal following these techniques) will be the same. Thus, the risks of environmental contamination and human exposure through disposing of radioactive material remain the same. **However, with less waste disposed of and the waste being more stabilized before disposal, these techniques may reduce the number of handling and transportation accidents but not necessarily their severity.**

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[20] 53 Federal Register 185, Sept. 23, 1988.

[21] To justify this decision, EPA regional offices can cite Section 1006 of RCRA. It states "nothing in this chapter shall be construed to apply to (or to authorize any State, interstate, or local authority to regulate) any activity or substance which is subject to [numerous laws including] the Atomic Energy Act of 1954 except to the extent that such application (or regulation) is not inconsistent with the requirements of such Acts."

Waste stabilization techniques are an important component of waste management, as is clearly indicated by the failure of past disposal practices to prevent radionuclide migration. NRC regulations do not require generators to stabilize Class A LLW. Stabilization, however, is a relatively inexpensive method of reducing the risk of environmental contamination. **By stabilizing Class A waste, which is about 97 percent of LLW, more assurance may be gained in the stability of disposal sites.** However, under certain environmental conditions (e.g., low precipitation) and given certain engineered disposal designs, the potential gain in short-term and long-term site stability may not justify stabilizing Class A waste.

With Class B and C wastes, it is difficult to predict with high certainty the long-term stability of various waste forms and container technologies. This uncertainty is primarily due to the relatively small database on their behavior. Furthermore, the variability in geochemical conditions encountered in a disposal site make it difficult to model site conditions. Nonetheless, the stability of most wastes can be significantly improved by using a combination of containment techniques.

Stabilization of different mixed LLWs requires more research to determine which technique or combination of techniques are most appropriate. EPA recommends monitoring the Superfund Innovative Technologies Evaluation Program for information on new techniques (15).

The uncertainty about the long-term stability of solidification and containment materials implies that long-term in-situ testing of waste stabilization materials will be necessary to manage LLW disposal sites. Test results can provide the scientific community, policymakers, and the public with the necessary information to plan for the *next generation* of disposal facilities.

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Chapter 6

Disposal Technologies

OVERVIEW

Most low-level radioactive waste (LLW) generated in the United States over the last 40 years has been disposed of by shallow-land burial. Unfortunately, at three of the Nation's six commercial disposal facilities, water infiltrated into the shallow trenches and in some cases caused radioactive contaminants to migrate into the surrounding environment. **Preventing water infiltration into disposal units is the key to safe disposal of LLW and mixed LLW.**

Disposal facilities that are well-designed, well-constructed, and well-maintained should be able to safely isolate LLW and/or mixed LLW for a few hundred years, and even longer if they are well-maintained throughout the operating period and post-closure care period. The disposal industry's ability to construct water-tight disposal facilities will certainly improve with experience, primarily from building new facilities and monitoring their long-term performance. **Since the integrity of these facilities will degrade over time, long-term monitoring may be advisable for as long as the waste remains harmful.**[1]

Gently sloping covers to the facilities, called caps, can be made of a variety of natural materials (e.g., clay) and man-made materials (e.g., synthetic membranes). In humid areas, these caps are generally composed of multiple layers of these various materials so that precipitation is kept from entering disposal units. If the cap leaks, below-grade facilities buried in impermeable clay may fill with water, unless they are pumped, thereby creating a "bathtub" effect. Water infiltrating into above-grade tumuli and earth-covered vaults can be drained (via gravity) into external collection basins and then monitored.

Unit disposal costs for most Class A LLW in 1989 average just over $40 per cubic foot. These costs will probably rise in 1990 when the surcharge to these States, allowed under the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA)[2], increases from $20 to $40 per cubic foot. Unit disposal costs at new disposal sites will undoubtedly be higher than today's costs for several reasons: 1) the presence of more small-scale disposal facilities with higher per unit disposal costs, 2) the use of more expensive technologies for waste packaging and disposal, 3) host community compensation packages, and 4) extended long-term care periods.

The development of better combinations of soil layers and synthetic membranes in multilayered caps could improve the long-term performance of disposal facilities. In-cap monitoring systems also could be more widely used so that leaks in the cap can be located and the cap repaired quickly.

INTRODUCTION

The goal of disposal is to isolate LLW and mixed LLW during the the time it poses an undue risk to humans and the environment. Since the toxicity and longevity of risk associated with different waste constituents varies, the required level and time period of containment depend on the concentration of the particular waste constituents. The Nuclear Regulatory Commission (NRC) requires that Class A LLW be contained for up to 100 years, Class B for 200 to 300 years, and Class C for up to 500 years. These requirements are based on the half-life of the radionuclides in the waste, the types of radiation emitted, and potential pathways to humans. These containment periods and the structural stability requirements of the waste are designed to ensure that an inadvertent intruder would not be exposed to radiation that poses an undue health risk to the individual. The Environmental Protection Agency (EPA) does not set similar containment periods for hazardous waste. It does, however, require that no migration occur during the post-closure care period—a period that lasts 30 years unless monitoring data support that this period be shortened or lengthened. However, unlike LLW, the toxicity of some hazardous waste (e.g., heavy metals and some synthetic organic chemicals) does not significantly decrease with time.

Disposal technologies for LLW and mixed LLW generally involve burial of the waste beneath the Earth's surface. Disposal technologies typically provide waste isolation in two different ways. First, shielding of the radioactive material is provided by concrete and/or layers of earth. Second, disposal facilities are designed to minimize the infiltration of water into the waste and any subsequent migration of dissolved waste constituents into the surrounding environment. **Infiltration can be minimized in three ways: by locating the disposal site in a relatively dry environment; by designing the disposal facility so that any precipitation quickly runs off the site, rather than percolating into the facility; and/or by surrounding the waste with water-resistant material, such as concrete coated with a waterproofing material.**

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[1] Determining the harmful period will depend on the long-term toxicity of the radioactive and hazardous, as defined under the Resource Conservation and Recovery Act, constituents in the waste.

[2] Public Law 99-240, Jan. 15, 1986.

Mixed LLW was included with other LLW and disposed of at commercial LLW disposal sites until November 1985. Since that time, mixed LLW is required to be disposed of at facilities designed to meet both NRC regulations for LLW and EPA regulations for hazardous waste. However, no such disposal facilities yet exist. Since waste disposal facilities for mixed LLW will probably require at least another few years to construct and license, most mixed LLW will have to remain in storage until the States and compacts develop mixed LLW disposal facilities. If it is assumed that 3 to 10 percent[3] of the LLW volume generated a year is mixed LLW and that all of this waste is stored,[4] about 130,000 to 430,000 cubic feet of mixed LLW will be in storage by the end of 1992.

After a brief history on LLW disposal, various waste isolation technologies will be described with emphasis on the near-surface, underground disposal techniques now being developed for both LLW and mixed LLW. Much of this material addresses the suitability of different disposal facility designs for different regions of the United States, particularly the humid regions in the East and the arid regions in the West. The last section of this chapter addresses disposal costs.

HISTORICAL BACKGROUND

Early Experience

Between the mid-1940s and the late 1970s, the majority of commercial LLW (as well as defense LLW) was stacked in shallow trenches and subsequently covered with several feet of soil. This disposal technique, which is illustrated in figure 6-1, is commonly called **shallow-land burial** (SLB). In the 1950s, the Atomic Energy Commission (AEC) established interim-disposal sites for commercial LLW at unlicensed, federally owned defense facilities near Oak Ridge, TN, and Idaho Falls, ID, until commercial facilities could be sited. By the early 1960s, there were three commercial disposal facilities operating at Beatty, NV; West Valley, NY; and Maxey Flats, KY. Within the next 10 years, three more facilities were opened at Richland, WA; Sheffield, IL; and Barnwell, SC.[5] See table 6-1 for the volumes of LLW disposed of at each of these facilities.

The late 1970s saw the closing of three commercial SLB sites, two due to radionuclides leaking from burial trenches. At West Valley, NY, some trench caps failed and the trenches filled with water to the point that water spread over the ground surface. The site was shut down in 1975. The earthen caps covering some of the burial trenches at Maxey Flats, KY, also failed, and water filling the trenches eventually spread as surface run-off. The trench water was pumped out and treated, and the site was closed in 1977. The Sheffield, IL, site was closed in 1978 when it reached its licensed capacity. Tritium migration has since been detected at Sheffield, but no health and safety hazard was or is deemed to exist (17). Remedial action, such as maintaining trench caps and pumping water from the trenches, is now occurring at all three sites.[6] **To date, monitoring efforts have not found significant amounts of radionuclide migration beyond the boundaries of these three inactive disposal sites** (17).

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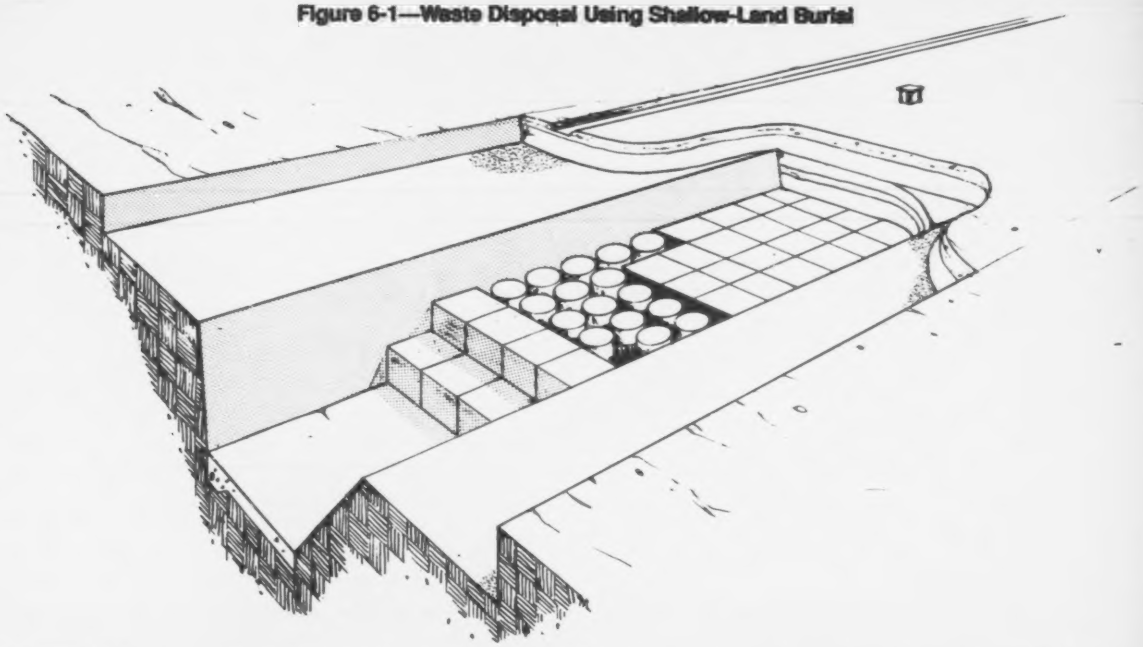
[3] As no national survey has been conducted, 3 to 10 percent is an estimate based on ad hoc surveys. If waste oil is listed by EPA as hazardous waste, this estimate would rise dramatically.

[4] Ad hoc State surveys and industry surveys indicate that the cumulative volumes of mixed LLW in general are holding steady and not increasing as would be expected since no disposal capacity has been available since November 1985. Some mixed LLW may be slipping through brokers and waste processors and entering LLW disposal sites undetected.

[5] Of all LLW so far disposed of by the United States, less than one-tenth of one percent (89,472 drums) was dumped into the ocean. All drums were deposited within 220 miles of our coastline during the 1946-70 time period when ocean dumping was practiced. Few records of these activities were kept, but sporadic monitoring of the few known sites has detected no adverse ecological impacts from these activities (8). Ocean dumping of LLW is not a politically viable option; it would require that an ocean dumping permit be approved of by EPA *and* both Houses of Congress within 90 days after receipt of an application.

[6] Both Maxey Flats and West Valley continue to "receive" wastes generated by onsite cleanup and water treatment operations.

Figure 6-1—Waste Disposal Using Shallow-Land Burial



SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts of Low-Level Radioactive Waste Disposal," prepared by Rogers and Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987.

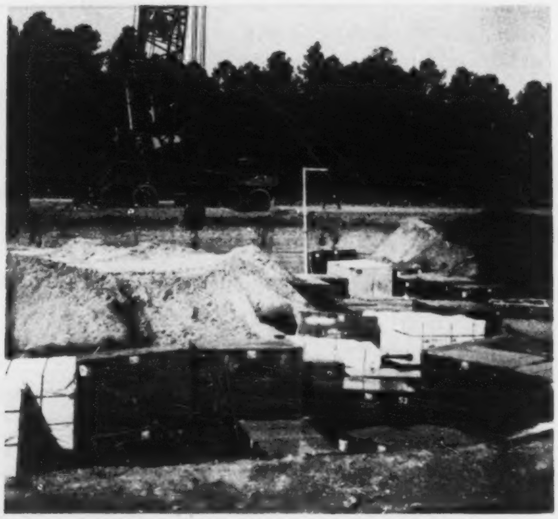


Photo credit: Gretchen McCabe

These two photographs illustrate the difference in disposal practices used at the humid site in Barnwell, SC (above) and at the arid site in Richland, WA (right). Both technologies are shallow-land burial for Class A waste, but the low precipitation in Washington does not necessitate stacking of Class A waste containers to minimize radionuclide migration.

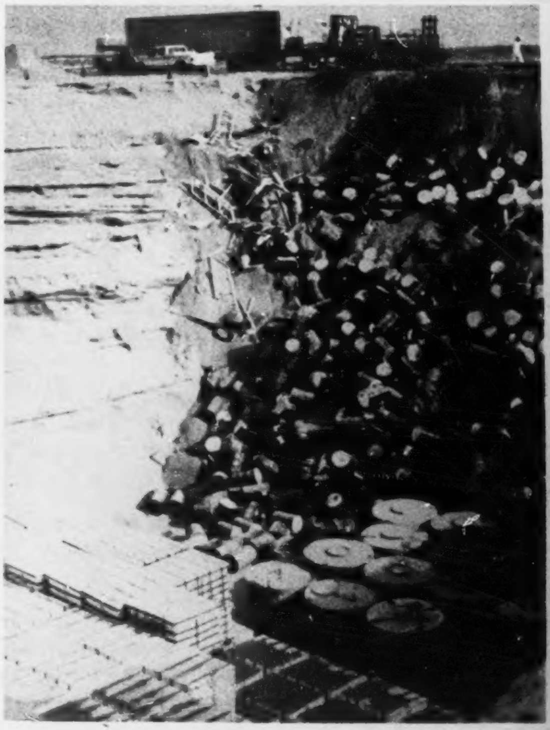


Table 6-1—Amounts of Commercial LLW Disposed of Through 1988

Disposal site	Years in operation	Cumulative amounts in 10^6 cubic feet	Approximate percent
Barnwell, SC	1971-present	20.6	45
Richland, WA	1965-present	10.8	24
Maxey Flats, KY	1963-1977	4.8	10
Beatty, NV	1962-present	4.0	9
Sheffield, IL	1967-1978	3.1	7
West Valley, NY	1963-1975	2.5	5
Total		45.8	100

SOURCE: U.S. Department of Energy, Draft, *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1989.

Significance of Past Problems

Radioactive waste at land-based disposal sites can pose a human health hazard in four ways. First, radionuclides can be leached out of the waste by infiltrating water thereby contaminating groundwater and/or surface water supplies. Second, radionuclides may be released in gaseous form into surrounding soils and ultimately to the atmosphere. Third, workers can be exposed to radiation from the waste during waste emplacement. Finally, humans may inadvertently uncover waste from a disposal facility at some time in the future. The relative importance of these release modes, which are discussed in more detail in ch. 4, vary considerably from one disposal facility to another.

Past environmental problems at the disposal facilities in Illinois, New York, and Kentucky can be traced to one or more of the following:[7]

- inadequate disposal facility designs;
- inadequate waste compaction prior to disposal;
- inadequate packaging of LLW containing liquids and highly mobile radionuclides, such as tritium;
- haphazard stacking of waste packages in disposal trenches;
- poor cap construction and/or maintenance;
- poor drainage of surface runoff; and
- an inability to monitor, detect, and remove infiltrating water from disposal trenches.

NRC's regulations for disposal sites (10 CFR Part 61) are aimed at minimizing water infiltration by avoiding these mistakes.

Many engineers familiar with past and present disposal practices believe that a well-designed and well-constructed disposal facility for LLW and/or mixed LLW can safely contain the waste for a few hundred years and probably longer. Disposal facilities at Richland, WA, and Beatty, NV, have both operated since the mid-1960s without any significant radionuclide migration. The disposal facility at Barnwell, SC, has operated successfully since 1971 despite its wet climate. Therefore, **past problems with the disposal of LLW should not be interpreted to mean that LLW cannot be safely disposed of in near-surface facilities.**

The performance of any LLW disposal facility will naturally reflect the disposal site characteristics, as well as the facility's design, construction, and management. Unfortunately, **it is not possible to accurately predict how long a particular disposal facility will perform at an acceptable level** for two reasons. First, the longevity of hazard associated with LLW and mixed LLW can range from several decades to a few hundred years and even longer for some wastes. These time periods extend well beyond the few decades of disposal site developers' experience. Second, many of the materials (e.g., impervious plastic membranes) and current facility designs have only been developed over the last several years and have yet to be subjected to long-term testing.

Given the Nation's limited experience with the design of LLW and mixed LLW disposal facilities relative to the length of risk from the waste, **it is important to recognize that uncertainties about the long-term performance of disposal facilities can be significant.** Disposal sites may contain minor undetected flaws. Facility designs may not behave exactly as predicted. Climate patterns may change. Institutional problems and mismanagement in the construction, operation, and maintenance of disposal facilities may occur and are often difficult to detect. These uncertainties generally increase with time. **Long-term monitoring programs supported with long-term care funds can compensate for these uncertainties.**

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[7] Similar problems with water infiltration and radionuclide migration have also occurred at several Department of Energy (DOE) defense sites in the United States, as well as at SLB facilities in Canada and in the United Kingdom (3).

GENERIC DISPOSAL TECHNOLOGIES

Four generic disposal technologies are described below based on their location relative to the Earth's surface. Several recent reports have compared these technologies in great detail using about two dozen different factors, including the level of technology development, degree of waste isolation, long-term stability and maintenance, worker safety, cost, ease of monitoring, and waste removal in the event of unacceptable contaminant migration, licensability, etc. (19, 9, 5).

All four generic disposal technologies, if properly implemented, could probably provide acceptable levels of waste isolation. Although no single disposal technology can be unequivocally judged "best" for all situations, **most States and/or compacts have chosen some type of near-surface, underground disposal technology as the most appropriate for isolating LLW and mixed LLW.** For ease of explanation, near-surface, underground disposal will be used as a baseline for evaluating the other three generic technologies.

Above-Ground Disposal in Concrete Vaults

With this technology, isolation is provided by a reinforced-concrete building constructed on the Earth's surface. As shown in figure 6-2, the building would not be covered with earth, but instead would simply have a flat or gently sloping concrete roof. Walls and the roof would probably range in thickness from 2 to 3 feet. The waste in the building would be isolated from humans and the environment as long as the integrity of the building is maintained. Some Canadian utilities presently use similar above-ground vaults for **storing** low-level and higher-level radioactive wastes for later disposal.

Although above-ground vaults can be easily sited and monitored, they have several disadvantages relative to near-surface, underground disposal facilities discussed below. First, above-ground facilities lack the protection of an earthen cover, thus leaving them exposed to degradation by wind, rain, and freeze-thaw cycles throughout most of the United States; long-term maintenance could be a problem. Second, since these facilities would be located above ground, there would be no surrounding soil to mitigate releases of radioactive material when the structure ultimately deteriorates. Third, inadvertent human intrusion is more likely; therefore, institutional control measures must be stronger.

Near-Surface Underground Disposal Facilities

Near-surface underground disposal technologies have been used for most LLW and mixed LLW so far generated in the United States. With most of these technologies, waste packages are disposed of within a few tens of feet of the Earth's surface and are capped with about 5 to 20 feet of soil, as illustrated in figure 6-1. To minimize cap subsidence and the subsequent infiltration of water, waste can be compacted and/or packaged in a stabilized form prior to disposal.

Well-designed and well-constructed near-surface disposal facilities can provide adequate levels of waste isolation if the waste can be kept dry. Ideally, a facility should be sited in an area away from surface water (including flash floods) and where travel time of any infiltrating precipitation to the groundwater table would be long and the travel of groundwater slow.[8] In areas where the groundwater time-of-travel is not long, concrete vaults can be used to increase the level of isolation and the stability of the disposal facility. Vaults also minimize the possibility of water infiltrating the waste.

The most commonly discussed near-surface disposal concepts include: trenches and below-grade vaults; above-grade tumuli and earth-covered vaults; and earth-mounded concrete bunkers, a combination of tumuli on top of below-grade vaults. These technologies will be discussed in more detail in the next section on near-surface disposal technologies.

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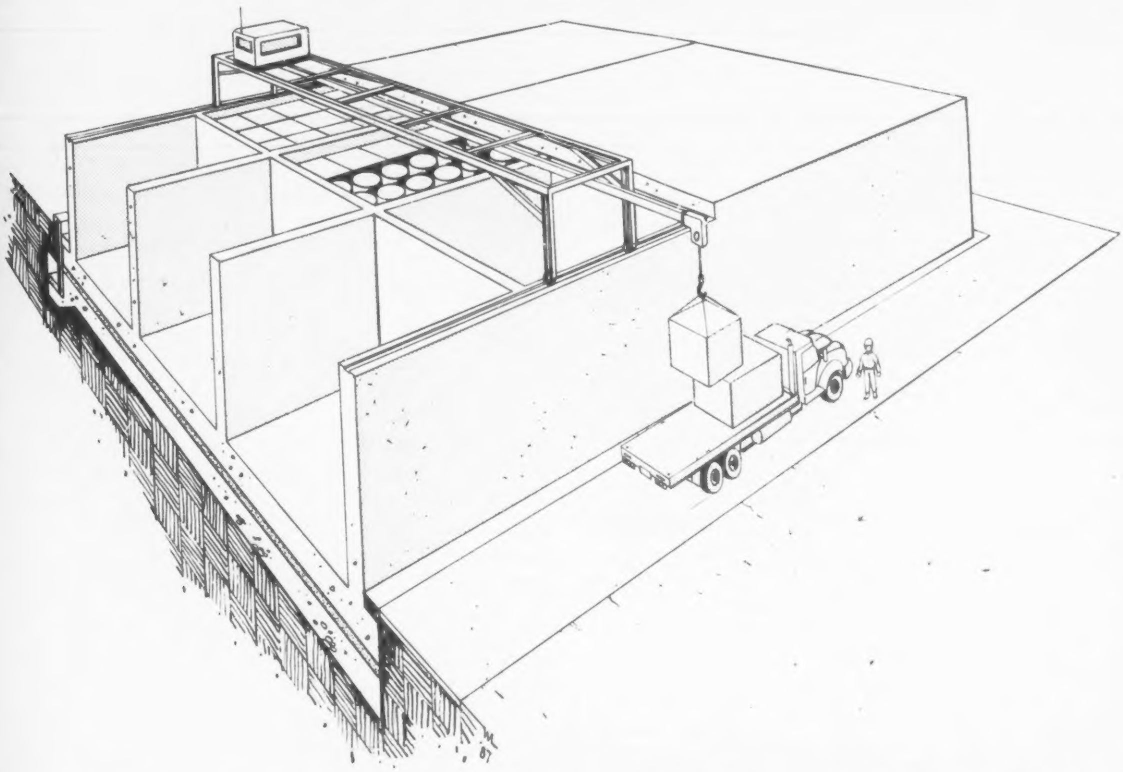
[8] EPA uses the term "groundwater time-of-travel" to judge the vulnerability of groundwater. It depends on precipitation rates, soil composition, orientation of sediment and rock layers, and depth to groundwater. EPA requires that the time for infiltrating water to reach the groundwater table and move 100 feet in any direction be greater than 100 years. Areas with a shorter groundwater time-of-travel are defined as having vulnerable hydrogeology and should be given special attention in designing a site (15).

Figure 6-2—Above-Ground Disposal in Concrete Vaults



SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts of Low-Level Radioactive Waste Disposal," prepared by Rogers and Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987.

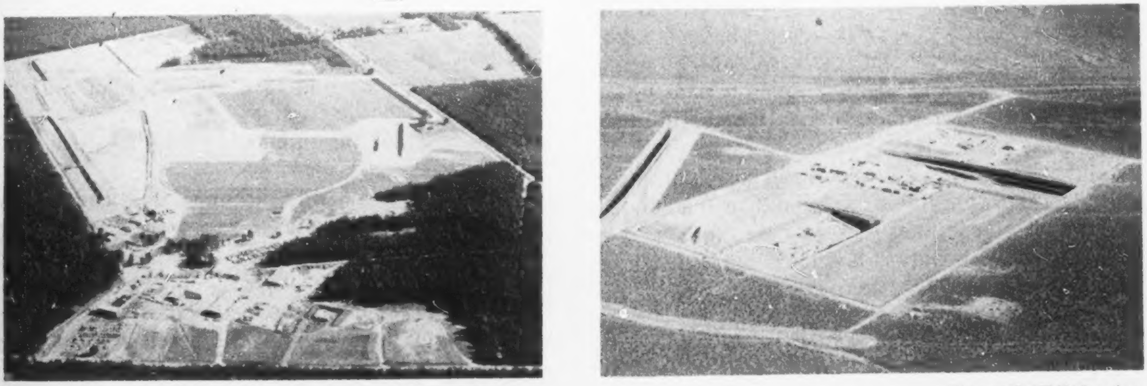


Photo credit: Chem-Nuclear Systems, Inc.

Photo credit: US Ecology, Inc.

The above two photographs illustrate the disposal site layout at a humid site (left) and at an arid site (right). Two-thirds of the site (in the foreground) at the arid site is for hazardous waste.

Intermediate-Depth Disposal in Augered Holes

LLW could be buried at intermediate depths of several tens of feet below the Earth's surface using augered holes. As shown in figure 6-3, this technology typically involves boring holes—measuring 8 or more feet in diameter—into the ground and possibly lining these holes with concrete or cement grout, typically measuring about 1 foot thick. After the hole has been filled with waste to within about 10 feet of ground level, grout is poured around the waste to form a solid cement-waste matrix inside the hole. A concrete cap is then placed on top of the waste, and the hole is backfilled with soil (2).

Over the last several years, augered holes with typical depths of 20 to 50 feet have been used on an experimental basis for the disposal of LLW and transuranic wastes at the Department of Energy's (DOE's) Savannah River National Laboratory, Nevada Test Site, and Oak Ridge National Laboratory. To maximize waste isolation, augered holes are normally located well above the water table.[9]

Augered holes would probably be acceptable for commercial LLW disposal; however, this option is not optimal for three primary reasons relative to near-surface disposal. First, the additional protection gained by disposing of the waste at depths of more than a few tens of feet below the Earth's surface is not necessary. Second, suitable sites may be difficult to find in some regions of the United States due to the presence of groundwater. Third, monitoring and possible removal of emplaced waste in the event of unacceptable levels of contaminant migration generally becomes more difficult as burial depths increase.

The use of augered holes is being phased out at the Savannah River National Laboratory in favor of buried concrete vaults, which are easier to operate and result in less worker exposure.[10]

Deep Disposal in Geologic Repositories

Deep geologic repositories, located at depths from a few hundred to a few thousand feet below the Earth's surface, are generally favored most by the scientific community worldwide for disposing of high-level and transuranic radioactive waste. The geologic formations surrounding a repository provide natural barriers to the migration of radionuclides by groundwater over the long-term. Engineered barriers, such as the waste form and waste package, enhance the isolation of the waste during the first few thousand years (13). After the excavated rooms in a repository are filled with waste, all shafts and tunnels are backfilled and sealed. A schematic view of a repository is shown in figure 6-4.

Several European countries plan to use geologic repositories for the disposal of low-level and intermediate-level waste. Sweden has developed a repository about 200 feet under the Baltic Sea. Finland plans to dispose of similar waste from its nuclear power plants in repositories about 300 feet beneath each plant. The United Kingdom is proposing to dispose of its low-level and intermediate-level waste in a repository 1,000 feet underground. West Germany disposed of some LLW in the Asse Salt Mine between 1967 and 1978. In the United States, DOE is presently planning to use deep geologic repositories constructed at depths of a few thousand feet for the disposal of commercial spent fuel and high-level and transuranic wastes generated from defense activities.

Geologic repositories for the disposal of LLW and mixed LLW is not optimal relative to near-surface technologies for several reasons. First, the additional protection gained by disposing of the waste at such depths below the Earth's surface is not necessary. Second, suitable repository sites may be very difficult to find in many regions of the United States, especially in the East where the time-of-travel of groundwater is short. Third, developing repositories of the small size required by most States or compacts would be prohibitively expensive. Finally, monitoring and waste removal from a backfilled repository (in the event of leaking waste or other problems) would be very difficult.

NEAR-SURFACE DISPOSAL TECHNOLOGIES

Near-surface technologies involve disposing of waste packages within a few tens of feet of the Earth's surface and capping the waste with 5 to 20 feet of soil. As shown in figure 6-5, disposal sites encompass: the actual waste disposal facilities, such as trenches or tumuli; any facilities for waste storage

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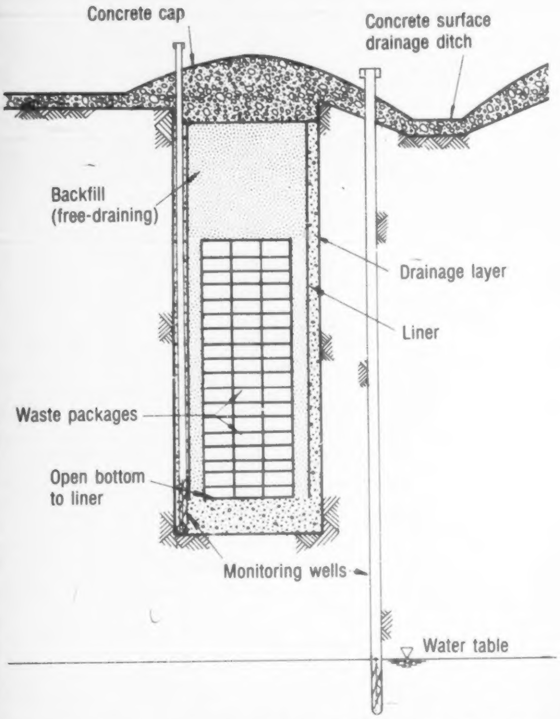
[9] Mike O'Rear, U.S. Department of Energy, Savannah River National Laboratory; Robert Sleemen, U.S. Department of Energy, Oak Ridge National Laboratory; and Robert Dodge, Reynolds Electric Engineering Corp., separate personal communications, June 1988.

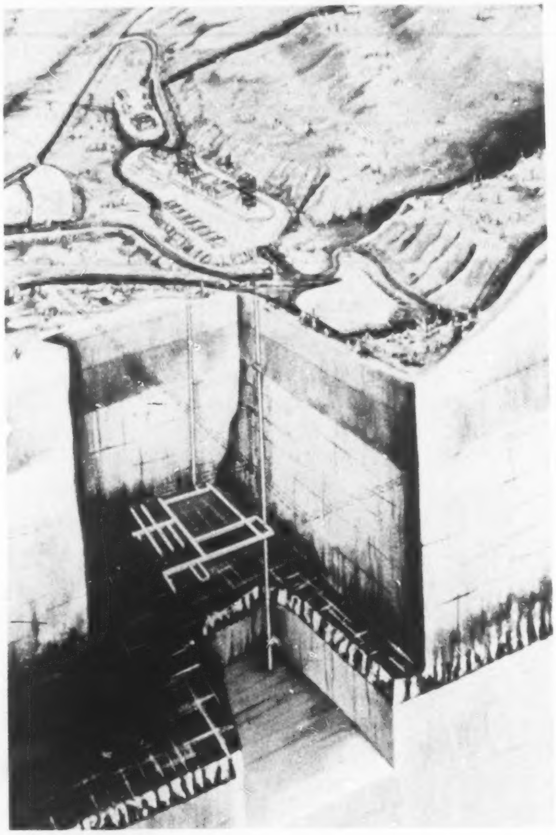
[10] Mike O'Rear, U.S. Department of Energy, Savannah River National Laboratory, personal communication, June 16, 1988.

Figure 6-3—Intermediate-Depth Disposal In Augered Holes



SOURCE: U.S. Nuclear Regulatory Commission, "Alternative Methods for Disposal of Low-Level Radioactive Wastes: Technical Requirements for Shaft Disposal of Low-Level Radioactive Waste," contractor report prepared by the U.S. Army Corps of Engineers, Waterways Experiment Station, NUREG/CR-3774, vol. 5, October 1985, p.22.

Figure 6-4—Schematic of Deep-Geologic Repository Design



SOURCE: Courtesy of U.S. Department of Energy.

and/or treatment; catchment basins for drainage water from the site; and unused buffer zones around and under the disposal units for monitoring and naturally dispersing any releases of waste constituents from the disposal units. Private firms will most likely operate these facilities; however, State governments will retain title to the land. During the two-to-four decades of site operation, disposal activities will be conducted in accordance with the general conditions of a facility license issued by NRC or an Agreement State.

On the one hand, there may be advantages to disposing of Class A, B, C, and mixed LLW in separate disposal facilities (at the same site). First, the disposal requirements for different types of waste are often quite different. Second, disposal units containing Class A waste will probably require monitoring for about 100 years; disposal units containing Class B, C, and mixed LLW may require monitoring well beyond that timeframe. Third, if different types of waste are separated, problems with one type of waste can be handled without the involvement of other waste types. On the other hand, there may be advantages to disposing of different types of wastes in the same facility. For example, Class B and C waste can be emplaced in the bottom of disposal trenches and covered with stabilized Class A waste.[11] This arrangement minimizes worker exposure to Class B and C waste and is less expensive than disposal in separate units.

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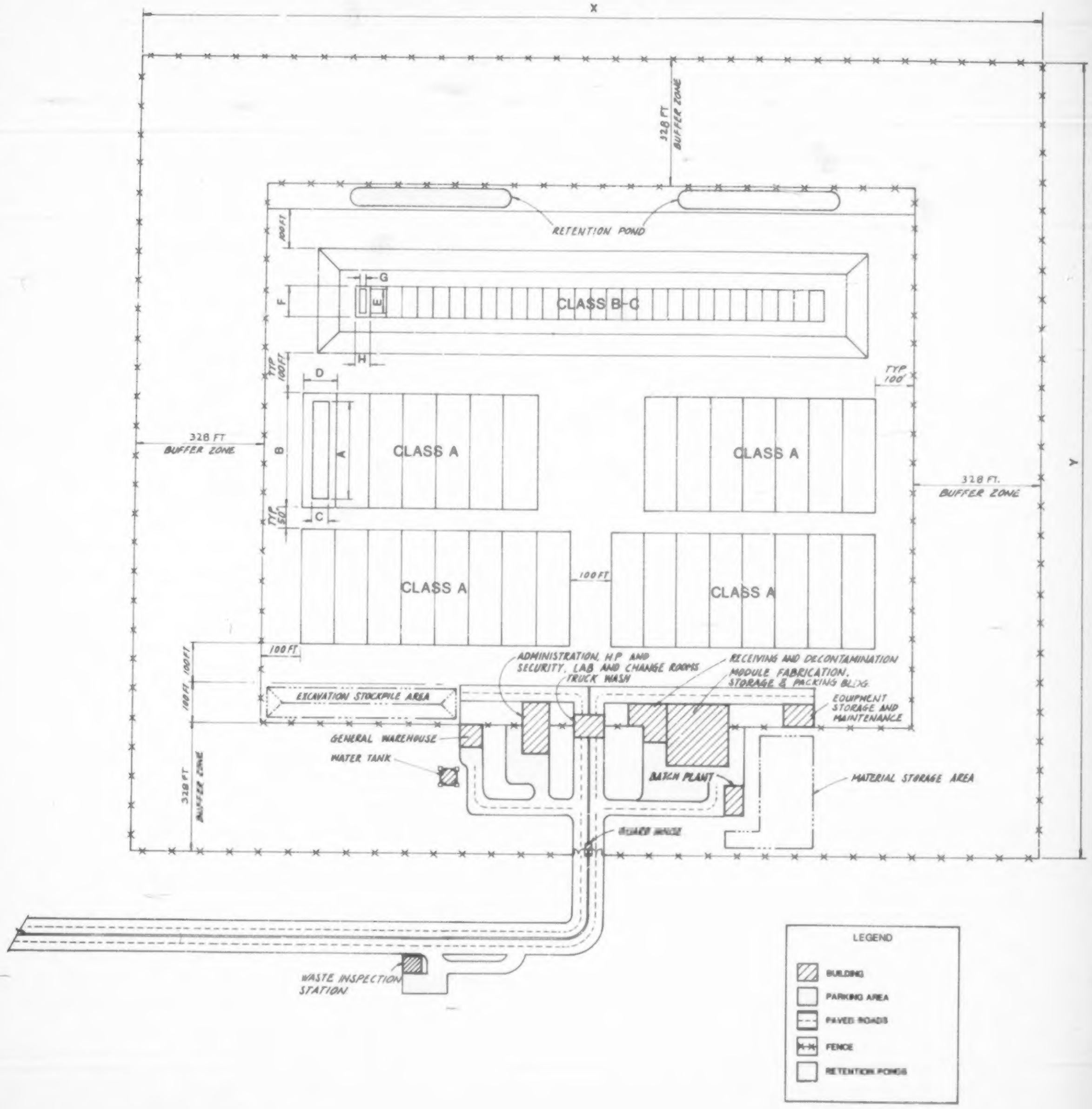
[11] NRC does not allow unstabilized Class A waste to be disposed of in the same unit with Class B or Class C (10 CFR Part 61.7[b][2]).

Figure 6-5—Layout of a Typical Disposal Site


X
Y
328 FT BUFFER ZONE
328 FT BUFFER ZONE
328 FT. BUFFER ZONE
328 FT BUFFER ZONE
RETENTION POND
100 FT
CLASS B-C
G
E
F
H
TYP 100 FT
D
B
A
C
TYP 50'
TYP 100'
CLASS A
CLASS A
CLASS A
CLASS A
100 FT
100 FT
100 FT
100 FT
EXCAVATION STOCKPILE AREA
ADMINISTRATION, HP AND SECURITY, LAB AND CHANGE ROOMS
TRUCK WASH
RECEIVING AND DECONTAMINATION
MODULE FABRICATION, STORAGE & PACKING BLDG
EQUIPMENT STORAGE AND MAINTENANCE
GENERAL WAREHOUSE
WATER TANK
BATCH PLANT
MATERIAL STORAGE AREA
GUARD HOUSE
WASTE INSPECTION STATION
LEGEND
BUILDING
PARKING AREA
PAVED ROADS
FENCE
RETENTION PONDS

SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts of Low-Level Radioactive Waste Disposal," prepared by Rogers and Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987.

Facility Siting—Natural Site Characteristics

Selecting an appropriate site for a waste disposal facility involves a general regional screening of many sites, eliminating unacceptable sites, and examining in more detail a few potentially good sites. In selecting a disposal site, NRC regulations (10 CFR Part 61.50) require that:

1. Primary emphasis be placed on site suitability in isolating the waste.
2. The site be capable of being characterized, modeled, analyzed, and monitored.
3. The projected population growth and future development shall not affect site performance.
4. Areas of known natural resources must be avoided if their exploitation would damage the site performance.
5. The site must be well-drained, free of ponding, above the 100-year flood plain, and away from coastal high-hazard areas or wetlands.
6. Upstream drainage areas must be minimized to decrease the amount of run-off that could erode a disposal unit.
7. The site must provide sufficient depth to the water table so that groundwater does not intrude waste packages.
8. Groundwater shall not be discharged to the surface within the disposal site.
9. Areas of active tectonic processes (e.g., faulting, folding, seismic activity, or volcanism) shall be avoided.
10. Areas of active surface geologic processes (e.g., erosion and slumping) shall be avoided.
11. The site shall not be located where nearby facilities or activities would damage performance of the site.

EPA has very similar siting criteria that they call location standards (14). Although these standards have not been finalized, NRC and EPA developed joint siting guidelines for commercial mixed LLW disposal. In addition to siting criteria listed above, the joint guidelines stipulate (22):

1. The site should provide a stable foundation for engineered containment structures.[12]
2. Areas of highly vulnerable hydrology should be given special attention. Disposal sites located in such areas may require extensive, site-specific investigations that could restrict or modify a facility's design or operating practices. However, finding a site located in an area of vulnerable hydrogeology alone is not considered sufficient reason to prohibit siting.

Waste Form and Packaging

In the past, water infiltration into waste disposal trenches has been caused or aggravated by the compaction and settling of physically unstable waste after disposal and by the consequent collapse of the overlying cap into disposal trenches. **Compacting the volume of all LLW and mixed LLW to the maximum extent practical prior to disposal will prevent many of these problems**. (See ch. 5 for waste minimization and treatment techniques.) NRC regulations require that Class B and C waste remain physically stable for at least 300 years. Some States and compacts may require that Class A waste be stabilized too.

High-integrity containers (HICs) and concrete "overpacks" containing several waste canisters are used to provide added structural stability, water resistance, and shielding for the waste (see figure 6-6). These containers also simplify the loading of waste into a disposal facility and the removal of waste from a facility should removal ever become necessary or desirable. These containers have wall thicknesses ranging from several inches to 2 feet, depending on shielding requirements. Structural stability of the waste is less important if the waste is either encased in grout after emplacement or placed in a concrete vault.

Engineered Features

Disposal Unit

After volume reduction and waste preparation, the waste is transferred to a disposal unit, which may have a dirt floor, a concrete loading pad, or an enclosed containment vault located in a trench (i.e., below-grade) or at ground level (i.e., at-grade). The loading surface of disposal units is typically sloped gently toward one or more sumps, which collect any infiltrating water. The loading surface may be underlain by a layer of gravel and an impermeable

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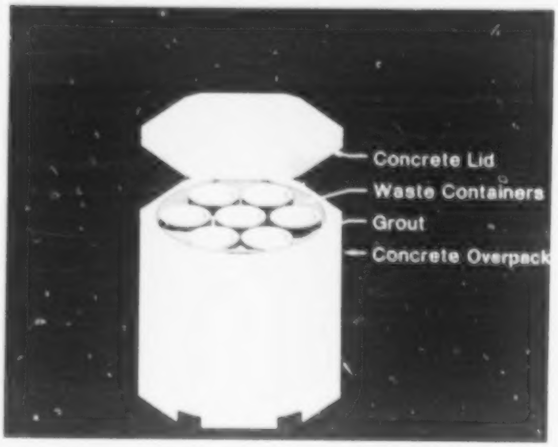
[12] Certain soils and geologic settings (e.g., karst) may be prone to subsidence or shifting when soil moisture or groundwater conditions change. It is not clear what types of soil are most desirable for a disposal facility. In permeable soils, infiltrating water can become contaminated and slowly percolate downward into groundwater aquifers. In impermeable soils, infiltrating water can fill disposal facilities like a bathtub and overflow into adjacent surface water supplies. EPA modeling studies indicate, however, that LLW disposal facilities situated in soils with low permeabilities may be safer than comparable facilities situated in well-draining, high-permeability soils (1).

Figure 6-6—Low-Level Radioactive Waste Overpack



SOURCE: Courtesy of Westinghouse Electric Corp.

barrier that slopes toward additional water collection sumps.

Disposal units generally cover an area of several hundred to 1,000 square feet, with waste stacked a few tens of feet high. For small volume disposal facilities, disposal units may be sized to hold a year's supply of waste. Adequate space between disposal units may ease monitoring and waste removal should it become necessary. After a disposal unit is filled with waste, the unit can be surrounded by a layer of gravel to promote drainage of infiltrating water to collection sumps.

If concrete vaults are not used, soil, sand, or gravel can be used to fill the space between the waste packages. This type of fill material allows water to rapidly drain through the waste but helps to stabilize the waste packages in the disposal unit. Added stability could be important over the long-term as the waste packages degrade and the cap settles. These fill materials also allow easy removal of the waste, if such action ever became necessary after disposal.

Another alternative for stabilizing waste in a trench or tumulus involves injecting cement grout into and around the waste packages. On the one hand, grouting increases the stability of the stacked waste packages over the short- and long-term and helps prevent any infiltrating water from percolating around or through the waste (at least over the short-term). On the other hand, grouting makes it much more difficult to remove the waste from the disposal unit should such action ever become necessary.

Photo credit: US Ecology, Inc.

LLW packages being transferred onto the dirt floor of a shallow-land burial trench.

Concrete containment vaults add structural stability to the disposal unit, help to prevent any infiltrating water from coming in contact with the waste, and provide an intrusion barrier around the waste. Walls are typically 2 to 3 feet thick; ceilings may range from 3 to 6 feet thick. Waste containers may be loaded into a vault through an open side or top, which is sealed after the vault has been filled. Vaults are designed to support their own weight, as well as the weight of the enclosed waste and overlying soil cover.

To evaluate the suitability of concrete for such vaults, DOE's Brookhaven National Laboratory

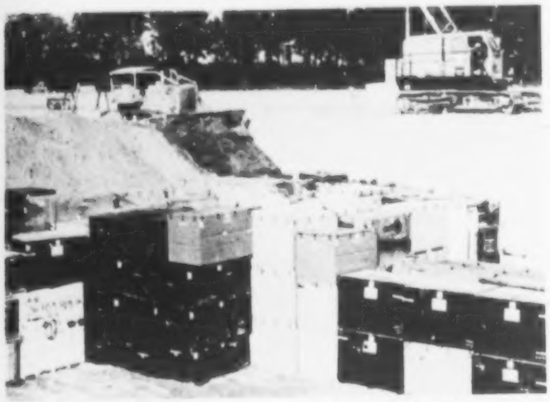


Photo credit: Chem-Nuclear Systems, Inc.

Stacked fill material being moved over waste containers in a shallow-land burial trench.

conducted an in-depth analysis of both ancient and contemporary concretes used throughout the world (6). The study found that some ancient concretes have performed adequately for 2,000 years or more. Although modern concretes have not been in use for much more than a century, there are many examples of these concretes performing adequately for periods spanning several decades and a few for periods of about 100 years (6).

Considering the harsh conditions that ancient concretes have withstood and the relatively benign conditions expected at most near-surface disposal facilities, **it should be possible to make concrete durable enough to last for a few hundred years and perhaps longer** (6). Some predictive models even indicate that concrete will last longer than 1,000 years; however, beyond about 500 years, the uncertainty of such predictions increases.[13]

After waste is emplaced in a vault, the space between the waste packages can be left open or filled with soil, sand, gravel, or cement grout if added stability is needed.[14] Added stability could be important over the long-term as the vault degrades and the cap settles. Emplacing fill material between waste packages is quite easy for top loading vaults, but somewhat more difficult for side loading vaults where working space is needed between the uppermost layer of waste and the vault ceiling.

Cap

After a disposal unit is filled with waste packages, it is covered with a gently sloping, single- or multi-layered cap. **The cap is the barrier with the most potential for diverting the greatest amount of precipitation away from disposal units. In addition, it is the feature of the disposal facility that is easiest and cheapest to repair, replace, or to cover over if infiltration does occur.** The long-term integrity of a cap is dependent on the cap design as well as the stability of the material underneath the cap, including the waste, the disposal unit, and the backfilled material around the disposal unit.

As shown in figure 6-7, caps may be composed of multiple layers of different soil types and one or more interspersed impermeable synthetic membranes. These membranes can provide an excellent barrier against infiltrating water for the lifetime of the membranes, which typically spans a few decades. During this time, layers of compacted clay (e.g., bentonite) within the cap will naturally consolidate, thereby providing a long-term and hopefully permanent barrier against infiltrating water. Layers of gravel overlying the clay allow for drainage and lateral transport of water to surface drainage ditches adjacent to each disposal facility. A layer of cobblestones within the cap can provide a barrier to intrusion by burrowing animals. All these layers would probably be protected with a 2- to 3-foot surface layer of native soil.[15]

The thickness of the cap may range from 3 to 6 feet for Class A and B waste. A cap thickness of at least 16 feet is required over disposal units containing Class C waste. Alternatively, a thinner cap can be used if the Class C waste is covered by an intrusion barrier (e.g., concrete slab) with a lifetime of at least 500 years. Due to the adverse effect of freezing on clay minerals, layers of clay have to be buried a few feet below the lowest level of frost penetration, which ranges from less than a foot in the mild climates of some southern States to 4 or 5 feet in some northern States. As the thickness of the cap increases, the required strength of a vault and the height and breadth of the cap have to be increased.

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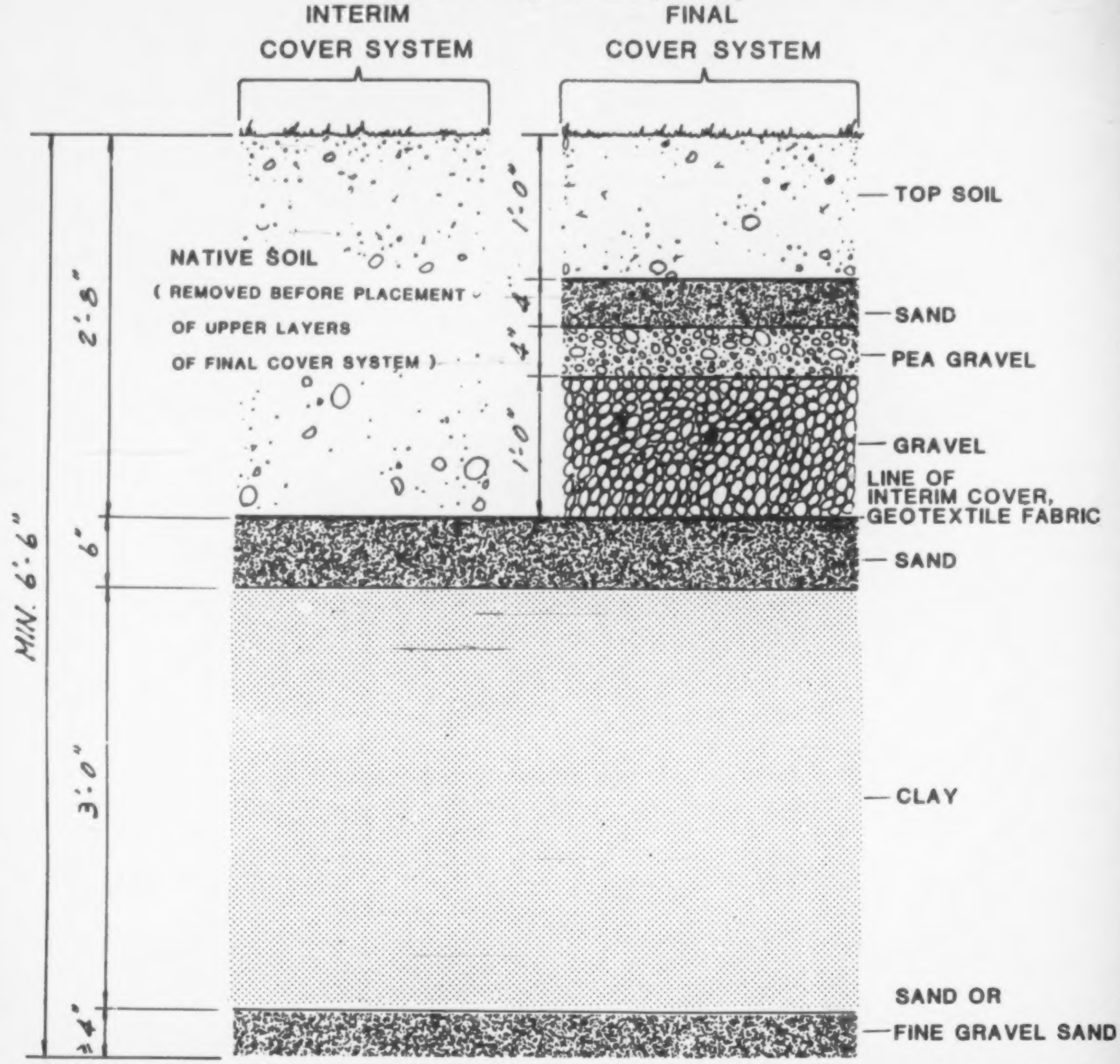
[13] OTA workshop on disposal technologies, Salt Lake City, Utah, Mar. 6, 1989.

[14] Grouting, however, will make waste removal very difficult if such action ever becomes necessary.

[15] In arid regions, all of these layers would likely be unnecessary.

Figure 6-7—Typical Multilayered Cap


INTERIM COVER SYSTEM
FINAL COVER SYSTEM
NATIVE SOIL
(REMOVED BEFORE PLACEMENT OF UPPER LAYERS OF FINAL COVER SYSTEM)
TOP SOIL
SAND
PEA GRAVEL
GRAVEL
LINE OF INTERIM COVER, GEOTEXTILE FABRIC
SAND
CLAY
SAND OR FINE GRAVEL SAND
MIN. 6'-6"
2'-8"
6"
3'-0"
4"
1'-0"
4"
4"
1'-0"

SOURCE: U.S. Department of Energy, "Prototype License Application: Safety Analysis Report Belowground Vault, Vol II: Appendices A-H," app. B, prepared by Rogers & Associates Engineering Corp. for the Nuclear Energy Low-Level Waste Management Program, DOE/LLW-72T, October 1988.

Most caps have surface slopes ranging from a few degrees on top of the disposal unit to a maximum of about 15 degrees along its sides.[16] Gently sloping cap surfaces may be planted with shallow-rooted vegetation. In arid regions it may be difficult to support vegetation on the cap. Rip rap (medium-size gravel) may be used to prevent erosion from infrequent flash flooding. The cap itself usually extends laterally a few tens of feet beyond the disposal unit and terminates at impervious lateral

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[16] EPA technical guidance calls for a more gradual slope—one that ranges between 3 and 5 percent and the erosion rate is less than 2 tons per acre per year (16).

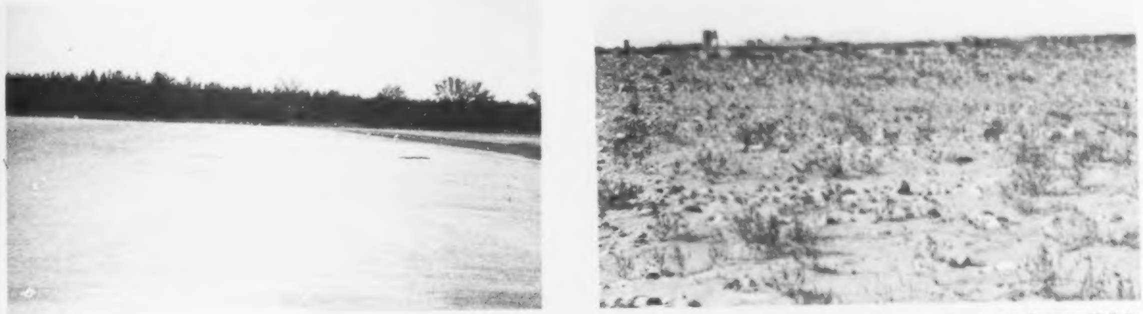

Photo credit: Gretchen McCabe

A contrast of the cap used over shallow-land burial trenches in humid regions (left) versus that used over arid regions (right). The cap on the left is at the Barnwell, SC and the cap on the right is at the Richland, WA site. The clay cap in Barnwell is monitored for subsidence for a few months and then covered with topsoil and planted with vegetation.

drainage ditches that carry surface runoff either offsite or to onsite retention ponds for monitoring, possible treatment, and subsequent offsite discharge.

Monitoring System

Past problems with radionuclide migration highlight the need for long-term monitoring of disposal facilities and sites. NRC or the respective Agreement State can independently monitor sites at its own discretion to ensure the accuracy of measurements taken by site operators. At a minimum, the site operator or custodial agency must continue periodic monitoring during the 100-year institutional period following site closure.

A monitoring program during site operation may include monthly or quarterly measurements of radiation levels in open and filled disposal units and periodic measurements of radionuclides in surrounding soil, vegetation, wildlife, air, surface water, and groundwater. The number of monitoring stations at a site and the sampling frequency may depend in part on the amount of annual precipitation and the past performance of the facility—the lower the rainfall and the better the performance, the less frequent the monitoring needs to be.

The best means for tracking the potential migration of waste constituents is to monitor the movement of precipitation over, around, and perhaps (in worst cases) through disposal facilities. As facilities are currently designed, the vast majority of precipitation falling on a disposal site is diverted away from the buried waste by the cap covering each disposal unit. Any migration of contaminants from the waste would be associated with small amounts of water that might infiltrate through the caps; if there is no leakage through the cap, there should be no migration of contaminants (assuming the disposal site is far removed from groundwater).[17]

Three primary locations for collecting and monitoring infiltrating water are often included in new disposal facility designs in humid regions. Sumps in the loading pads or vault floors collect water moving downward through the disposal units. Sumps in the gravel layers under the loading pads or vault floors collect water moving through the backfilled material surrounding the disposal units. Monitoring wells are also typically located around the perimeter of disposal sites. However, disposal facility designs have yet to incorporate a monitoring system into the lower layers of a cap so that leaks in the cap can be quickly detected and repaired before much water enters a disposal unit.

To minimize the migration of contaminants away from disposal units, any infiltrating water must *not* be allowed to accumulate in the disposal units and to saturate the waste. Infiltration can be prevented by pumping accumulated water out of disposal units or passively draining water (via gravity) to collection basins for monitoring, possible treatment, and offsite discharge. Most disposal site engineers believe that passive drainage that minimizes the dependence on human or mechanical measures is preferred. In some facility designs, the internal drainage collection pipes all run into a 6-foot-diameter concrete monitoring gallery under the site with a monitoring port for each drainage collection pipe. The more sumps there are, the easier it is to pinpoint the source of any leaks. However, it may be more difficult to maintain a more complex drainage and monitoring system.

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[17] NRC regulations prohibit the disposal of wastes with greater than 1 percent of free liquids; all liquids must be evaporated, solidified, or retained in absorbent material prior to disposal. Some States may also restrict the use of absorbent material and require the stabilization of all wastes.

Other Engineered Features

Many other engineered features can be incorporated into disposal facility designs to minimize the infiltration of surface water and to keep the waste as dry as possible. For example, the outside of concrete vaults can be covered with synthetic membranes, epoxy resins, bentonite panels, etc., to increase their resistance to water. The insides of vaults and concrete containers can be coated with epoxy resins, asphalt, synthetic liners, or other waterproofing materials. Open disposal units can be covered with some sort of mobile roof during filling to shelter the waste from precipitation.

General Designs of Near-Surface Disposal Facilities[18]

Most engineers who are familiar with the disposal of LLW and hazardous wastes believe that **acceptable near-surface disposal facilities for LLW *and* mixed LLW can be developed anywhere in the country using readily available materials and widely applied construction techniques**. Furthermore, they believe that **significant breakthroughs in technology are not necessary, imminent, or worth waiting for. The probability is high that disposal facilities that are well-designed, well-constructed, and well-maintained can safely isolate LLW and/or mixed LLW for a few hundred years and perhaps even longer.** Incremental improvements will come from construction experience and the long-term monitoring of facility performance.

Disposal facility designs now being developed by States and compacts often incorporate many of the natural site characteristics and engineered features described above. **The use of these features to prevent water infiltration, especially at sites located in humid regions, tends to increase the level of public confidence in the long-term performance of disposal facilities**. However, facilities that do not incorporate these features, especially those facilities in arid regions, should not necessarily be considered unacceptable.

Although disposal facility designs have improved over the last decade, **States must create an institutional process to ensure the proper siting, design, construction, and management of disposal facilities**. Using a more sophisticated and/or expensive facility design will not necessarily improve the long-term containment of the waste if the facility is not properly developed and managed. The consequence of inadequate design and shoddy construction and/or management may not be evident for many decades after a disposal facility has been closed. Moreover, adapting a good general design to fit the natural characteristics of a specific disposal site can be as or more important than choosing the general design itself.

Below-Grade Facilities

With below-grade facilities, the elevation of adjacent surface drainage channels is **above** the **highest** level of buried waste. (See figure 6-8.)

All commercial LLW disposal facilities in the United States have used ***trenches***, a disposal technology commonly referred to as **shallow-land burial** (SLB) (see figure 6-1). Typical trenches may be 20 to 60 feet wide, 20 to 40 feet high, and several hundred feet long. Trench floors are usually sloped a few degrees toward pumpable sumps located along the sides and at the ends of the trenches and are covered with a uniform layer of gravel for internal drainage. Once a portion of the trench has been filled with waste, it is normally covered with 3 to 10 feet of compacted soil from a newly excavated portion of the same trench or another. In many cases, a multilayered cap may be constructed over this fill material. Depending on the site characteristics, trenches may be spaced as close as 15 feet apart.

In light of the inadequate performance of SLB facilities in New York, Illinois, and Kentucky, nearly 80 percent of States and compacts have banned or restricted the use of SLB for isolating LLW (20). **"Improved" SLB is now practiced at**

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[18] This discussion is based primarily on information from the U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal," prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987; and from the New York State Energy Research and Development Authority, "Handbook of Disposal Technologies for Low-Level Radioactive Waste," June 1987.

the three existing commercial disposal facilities in South Carolina, Washington, and Nevada. The primary improvements mandated by NRC's 10 CFR Part 61 regulations involve segregating Class A, B, and C waste, stabilizing Class B and C waste, and using an intruder barrier or deeper burial for Class C waste. To date, **there has been no offsite migration of radionuclides at any of these three facilities**.

Due to past problems with SLB, some States and compacts have expressed much interest in using ***below-ground vaults***. As shown in figure 6-8, below-ground concrete vaults are underlain with a layer of gravel, and typically have sumps and a pump-out capability for removing infiltrating water. After the vaults have been filled with waste and sealed, the trenches are backfilled and typically covered with a multilayered cap.

Below-ground vaults measuring 100 feet long, 50 feet wide, and 20 feet high have been used at DOE's Savannah River National Laboratory for the disposal of defense LLW, which is comparable to commercial Class B and C waste.[19] Below-ground vaults have also been used for the retrievable **storage** of transuranic and other LLW at the Oak Ridge National Laboratory, in Canada, and in other foreign countries.

Above-Grade Facilities

With above-grade facilities, the elevation of adjacent surface drainage channels is **below** the **lowest** level of buried waste. (See figure 6-9.)

An above-grade ***tumulus*** is now being used on a demonstration basis for the disposal of Class A waste at the Oak Ridge National Laboratory. A concrete pad measuring 100 feet by 65 feet was first poured at ground level on top of a layer of gravel. Compacted waste is being placed into reinforced concrete containers measuring about 5 feet by 6 feet by 7 feet. These containers are then placed in two layers on the concrete pad. The stacked containers will be covered with layers of clay, an impermeable membrane, and soil to form a low-gradient mound with a relief of about 20 feet. Vegetation will be used to prevent cap erosion.[20]

A tumulus has also been proposed (see figure 6-9) for the disposal of Class B and C waste generated by the cleanup of a now-defunct spent fuel reprocessing operation located at the West Valley, New York, facility. According to present plans, the final dimensions of the tumulus over the vault will measure about 30 feet high, about 250 feet across at the base, and about 500 feet long. Slopes on top of the tumulus will be a few degrees; slopes along the sides of the mound will be about 15 degrees.[21]

In cases where additional long-term stability is required, the waste can be disposed of in ***earth-covered, above-ground vaults***. With this type of facility, the waste is placed inside a concrete vault constructed at ground level. Once the vault is covered with a cap, the facility will have the contour of a gently sloped tumulus. Such facilities have been proposed for waste disposal in humid regions of the United States, especially for Class B, C, and mixed LLW.

Earth-Mounded Concrete Bunkers

Earth-mounded concrete bunkers (EMCBs) have been developed and successfully used in France over the last two decades. Trenches are first filled to ground level with Class B and C waste, which is encased in concrete. Reinforced concrete is poured over the uppermost layer of waste, thereby forming large monoliths. Metal drums and/or concrete containers of Class A waste are then stacked on top of the concrete monoliths and covered with soil, giving the facility its tumulus shape. (See figure 6-10.)

There are two potential problems with this disposal scheme. First, EMCBs may have to be monitored and maintained for the 500-year lifetime of the Class C waste in the trenches even though Class A and B waste will have decayed within 100 years and 300 years, respectively. Second, dealing with potential problems with Class B and C waste might necessitate removal of the overlying Class A waste.

DEVELOPING SITE-SPECIFIC DISPOSAL FACILITIES

There are probably many acceptable ways in which different features can be incorporated into site-specific disposal facility designs. **Due to differences in site characteristics, especially annual**

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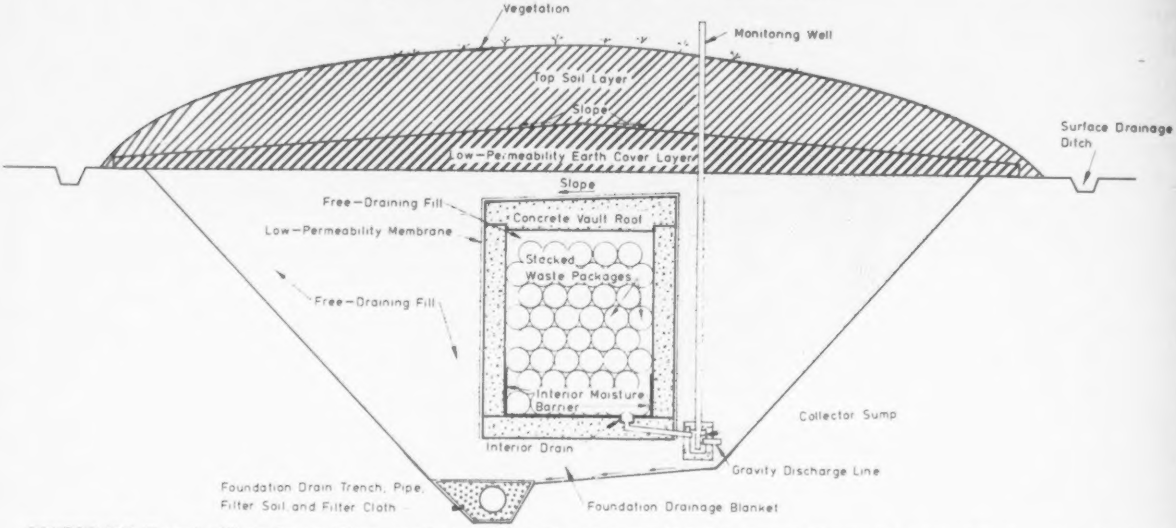
[19] O'Rear, op. cit., footnote 10.

[20] Robert Sleemen, U.S. Department of Energy, Oak Ridge National Laboratory, personal communication, June 16, 1988.

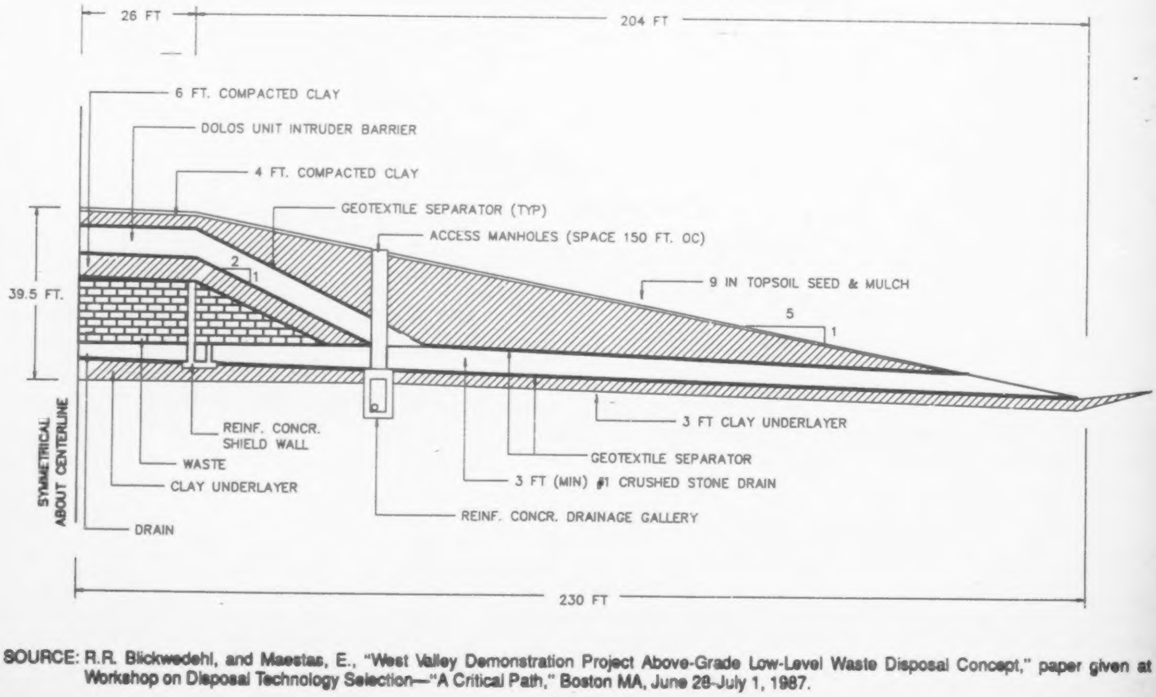
[21] Henry Walter, U.S. Department of Energy, personal communication on Sept. 28, 1989.

Figure 6-8—Below-Ground Vault Cross Section


Vegetation
Monitoring Well
Top Soil Layer
Slope
Surface Drainage Ditch
Low-Permeability Earth Cover Layer
Slope
Free-Draining Fill
Concrete Vault Roof
Low-Permeability Membrane
Stacked Waste Packages
Free-Draining Fill
Interior Moisture Barrier
Collector Sump
Interior Drain
Gravity Discharge Line
Foundation Drain Trench, Pipe, Filter Soil and Filter Cloth
Foundation Drainage Blanket

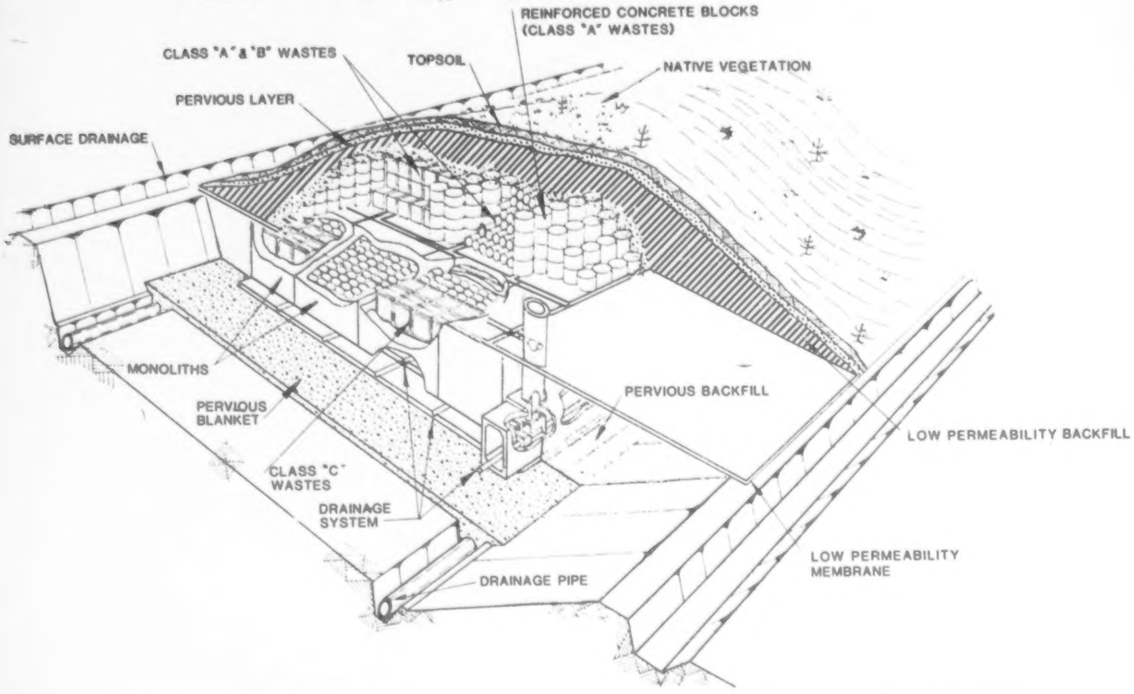
SOURCE: R.D. Bennett, "Waste Covers, Filters, and Drains," *Proceedings from The U.S. Department of Energy Ninth Annual Conference on Low-Level Radioactive Waste*, Denver CO, Aug. 25-27, 1987.

Figure 6-9—Above-Grade Tumulus Cross Section


26 FT
204 FT
6 FT. COMPACTED CLAY
DOLOS UNIT INTRUDER BARRIER
4 FT. COMPACTED CLAY
GEOTEXTILE SEPARATOR (TYP)
ACCESS MANHOLES (SPACE 150 FT. OC)
2
1
9 IN TOPSOIL SEED & MULCH
39.5 FT.
5
1
3 FT CLAY UNDERLAYER
REINF. CONCR. SHIELD WALL
GEOTEXTILE SEPARATOR
WASTE
3 FT (MIN) #1 CRUSHED STONE DRAIN
CLAY UNDERLAYER
REINF. CONCR. DRAINAGE GALLERY
SYMMETRICAL ABOUT CENTERLINE
DRAIN
230 FT

SOURCE: R.R. Blickwedehl, and Maestas, E., "West Valley Demonstration Project Above-Grade Low-Level Waste Disposal Concept," paper given at Workshop on Disposal Technology Selection—"A Critical Path," Boston MA, June 28-July 1, 1987.

Figure 6-10—Perspective View of an Earth Mounded Concrete Bunker



A perspective view of the Earth Mounded Concrete Bunker depicts the approximate locations of wastes which are separated according to level of activity. Class "C" wastes are embedded in concrete monoliths belowground while Class "B" wastes and stabilized Class "A" wastes are stored aboveground in earthen mounds over the concrete monoliths. A drainage network is provided within and around the structure to prevent the contact of water with the wastes and to provide collection and monitoring capabilities.

SOURCE: U.S. Nuclear Regulatory Commission, "Alternative Methods for Disposal of Low-Level Radioactive Wastes: Technical Requirements for an Earth Mounded Concrete Bunker," contractor report prepared by the U.S. Army Corps of Engineers, Waterways Experiment Station, NUREG/CR-3774, vol. 4, Oct. 1985, p.6.

precipitation and time-of-travel of groundwater, there is no one disposal facility design that is optimum for all regions of the country. For example, a facility design that might be suitable for a site in an arid region might be inappropriate for a site in a humid region, and visa versa.[22] **With increasing experience and long-term monitoring, some disposal facility designs will undoubtedly prove superior to others.**

Selecting an Appropriate Facility Design for LLW

Both below-grade and above-grade facility designs have advantages and disadvantages when used in regions of the country with high or low precipitation. Regardless of the design chosen, it is of utmost importance to keep LLW and mixed LLW dry.[23]

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[22] Wind erosion and intense periods of rainfall are concerns in arid environments. An above-grade structure may require more active maintenance in arid climates than a below-ground structure. Furthermore, a clay cap used in humid regions may dry out and crack in arid regions.

[23] Many other parameters can be used to evaluate the desirability of disposal facility designs. These parameters include: protection of the general population, protection of inadvertent intruders, worker protection, land requirements, costs, long-term stability, development time, previous operating experience, monitorability, licensability, ability to remove the waste after disposal, etc. More detailed comparisons of disposal facility designs are provided in U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal," prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987; New York State Energy Research and Development Authority, "Handbook of Disposal Technologies for Low-Level Radioactive Waste," June 1987; and Illinois Department of Nuclear Safety, "Technical Considerations for Low-Level Radioactive Waste Disposal in Illinois," draft summary, November 1987.

Regions With High Precipitation

As engineered features decrease the potential for water infiltration, many of these features will likely see extensive use in humid regions of the United States, principally the East. In fact, the level of public confidence in the long-term performance of a waste disposal facility may depend on incorporating more of these design features. Design engineers generally agree that **"passive" features, such as natural down slope drainage, are generally more reliable over the long-term than "active" features, such as pumps.**[24]

If a disposal site is located in an area with a long groundwater time-of-travel and far from flood-prone areas, **infiltration of precipitation will be the most likely cause of buried waste coming into contact with water**. Therefore, a well-designed and well-maintained cap is used to prevent this scenario. If the cap is 100 percent effective, there should be no post-disposal migration of waste constituents from either below-grade or above-grade facilities. However, if infiltration occurs, the facility design will likely affect the rate at which water accumulates inside the facility, the rate at which contaminants leach from the waste, and the subsequent migration of contaminated water from the waste disposal facility.

Precipitation leaking into **below-grade trenches** tends to accumulate in sumps located at the ends or sides of the trenches. If water accumulating in the sumps is not pumped out, the trenches **can fill with water like a "bathtub."** Water in the trenches will eventually saturate the waste and will leach contaminants from it. Contaminated water will then percolate through the floor and walls of the trench into the groundwater and/or overflow at ground level. The same sequence of events can occur with below-grade vaults, but perhaps to a lesser degree. Any water pumped from trenches or below-ground vaults can be monitored and treated for contaminants and subsequently discharged offsite.

The "bathtub" effect is not a problem with above-grade tumuli or earth-covered, above-ground vaults. Instead, any water infiltrating through the cap is usually collected above an impermeable barrier (e.g., concrete loading pad, or a synthetic liner/clay layer below the disposal unit) that prevents downward migration of water below the lowest level of waste. Rather than accumulating inside the facility and saturating the waste, this collected water is typically channeled passively (via gravity) through buried pipes to external collection ponds, where it can be monitored, treated if necessary, and subsequently discharged offsite.

The ability to account for any water that infiltrates through the cap and into the disposal facility also varies between below-grade and above-grade facilities. With above-grade facilities, precipitation will either run off the cap, drain through the facility and into external collection basins, or remain inside the facility. With below-grade facilities, infiltrating water might also leak laterally through the vault or trench walls or downward through the vault or trench floor, if it is not immediately pumped out. Only monitoring wells around the disposal site perimeter would be able to detect any such leakage. Lining trenches and vaults with impervious natural or synthetic material will probably help contain infiltrating water inside below-grade facilities, but liners may also aggravate the bathtub effect and increase the likelihood that the waste will become saturated with water.

As shown in table 6-2, certainty about the performance of a disposal facility is high *if* the cap sheds all precipitation from the facility. However, if the cap is less than 100 percent effective, **the potential for accurately determining the fate of infiltrating precipitation is high for above-grade facilities with a good monitoring system, moderate for below-grade facilities with a good monitoring system, and low for any facility with a poor monitoring system**. In addition, in-cap monitoring systems would significantly improve engineers' ability to evaluate both the effectiveness of caps and the overall performance of above-grade and below-grade facilities.

Since the bathtub effect is an unlikely problem for above-grade facilities, they probably have a greater potential for keeping buried waste dry if the cap leaks. Given comparable monitoring systems, **above-grade facilities also provide a higher level of certainty about disposal facility performance than do below-grade facilities**. However, above-grade facilities do have disadvantages rela-

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[24] Some disposal experts believe that including too many engineered features into a facility design simply adds to its complexity and cost without necessarily improving its long-term performance. However, given the limited experience with different facility designs, engineers do not know at what point a facility may be considered overdesigned.

Table 6-2—Levels of Certainty About Disposal Facility Performance in Regions of *High* Precipitation

Good monitoring	Poor monitoring
Facility performance good Disposal facility design not critical High certainty about facility performance	**Facility performance good** Disposal facility design not critical Low certainty about facility performance
Facility performance poor *Above-grade facilities:* High certainty about facility performance and the need to treat infiltrating water *Below-grade facilities:* Moderate certainty about the nature of surface *and/or* groundwater contamination	**Facility performance poor** *Above-grade facilities:* Low certainty about facility performance and the need to treat infiltrating water *Below-grade facilities:* Low certainty about the nature of surface *and/or* groundwater contamination

SOURCE: Office of Technology Assessment, 1989.

tive to below-grade facilities. First, disposal sites with above-grade facilities occupy about 70 percent more land area than sites with below-grade facilities (10), as shown by the wider cap in figure 6-9. Due to increased land requirements for above-grade facilities, unit disposal costs are higher. Second, the broader surface area and steeper side slopes for tumuli could be more prone to erosion. Third, eventual unrestricted use of the disposal site may be limited by the ridge-swale topography.

Regions With Low Precipitation

Where there is no precipitation, there will be no infiltration of precipitation and no migration of waste constituents from either an above- or below-grade facility. **In regions of the country where annual precipitation is very low today and will probably remain so over the next few centuries, principally in the West, there seem to be no technical reasons for using the more elaborate above-grade facilities to dispose of LLW; below-grade facilities are adequate and likely preferable[25] in most arid regions.**

Selecting an Appropriate Facility Design for Mixed LLW

As described in chapter 3, NRC's 10 CFR Part 61 regulations emphasize physically stabilizing LLW to minimize cap subsidence and the subsequent infiltration of water. However, NRC-licensed facilities are *not* expected to contain all the waste (i.e., "zero release") for any period of time. Instead, the hydrogeologic environment surrounding the disposal facility is expected to dilute, disperse, and adsorb any leaking contaminants to acceptable levels during facility operation and after facility closure. NRC requires an institutional care period of up to 100 years following site closure (10 CFR Part 61.59). This period is to ensure that no undue risk is posed to public health and safety from the disposal site.

EPA controls the disposal of hazardous wastes in landfills through its regulations found in 40 CFR Part 264. The goal of EPA's regulations is to totally contain hazardous wastes. To do this, the bottom and sides of EPA-licensed facilities are lined with layers of clay and double synthetic material, forming a double-lined bathtub. Leachate collection systems are situated between the double liners to prevent any leaking contaminants from escaping into the surrounding environment. If leaks develop in both liners during operation or pose-closure, pumping and treating contaminated water from remediation wells surrounding the site can hopefully be used to control the migration of waste constituents. In such a case, EPA would likely require extension of the standard 30-year post-closure care period (40 CFR Part 264.117).

Over the last few years NRC and EPA have developed joint guidelines and joint guidance for siting and designing mixed LLW disposal facilities (22, 23). **These guidelines propose an above-grade facility as an acceptable design**. A multilayered cap forms an "umbrella" over the waste, rather than a bathtub under the waste. EPA's double liners and leachate collection systems are located beneath the waste where they can intercept infiltrating water and channel it via gravity to collection basins for monitoring, possible treatment, and offsite discharge.[26]

A few humid eastern States are planning to use earth-covered, above-ground vaults for mixed LLW disposal, since these facilities appear to be more reliable for isolating waste in humid areas than below-grade facilities.

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[25] The greatest environmental risk to an arid site may be from wind erosion and intense periods of rainfall; therefore, an above-grade structure would more likely be damaged than a below-ground facility.

[26] State and compact progress in developing mixed LLW disposal units is generally well behind their progress in developing disposal units for their nonmixed LLW. There are several technical and political factors causing this delay.

Arid States seem to prefer less elaborate, below-grade facilities rather than above-grade facilities. **If precipitation is not a problem, there seems to be no technical reasons for using above-grade facilities rather than below-grade facilities, or for using double liners and leachate collection systems beneath the waste**, as required by EPA's regulations. In fact, an above-grade facility could be inappropriate in arid regions due to wind erosion and/or water erosion from periods of intense rainfall that could damage it much more than a below-ground facility.[27]

Development Schedules

Designs for nonmixed LLW facilities must be approved by NRC or by Agreement States; designs for mixed LLW facilities must be approved by NRC or by Agreement States, *and* by EPA, or by a State with mixed waste authorization. Most host States are planning to obtain licensing/permitting authority from NRC and EPA for both LLW and mixed LLW facilities, since this approach appears to be the most expeditious. An optimistic schedule for developing a waste disposal facility, *barring nontechnical obstacles*, is shown in table 6-3.[28]

Regardless of the general disposal facility design chosen, **there are no *technical* obstacles preventing all States and/or compact regions from finding acceptable sites within their borders and designing, constructing, and licensing waste disposal facilities for LLW and mixed LLW. There are, however, institutional and political obstacles hindering facility development. This is particularly true for mixed LLW facility development.** Potential regulatory conflicts and inconsistencies and regulatory overlap and duplication between NRC and EPA have hindered mixed LLW disposal facility development (see chs. 1 and 3). Lawsuits have and likely will further delay development of both nonmixed and mixed LLW disposal units.

Phased Facility Development in Humid Regions

Multilayered caps have the greatest potential for diverting the vast majority of precipitation away from waste disposal facilities. However, caps must be compatible with site-specific facility designs and climatic conditions. For example, shallow-rooted surface vegetation must have an appropriate amount of precipitation and/or soil moisture for survival and growth.[29] Layers of clay within the cap also have to be buried a few feet below the lowest level of frost penetration to maintain the cohesiveness of the clay minerals.

It should be possible to develop a multilayered cap that is 100 percent effective in diverting precipitation away from a disposal facility for many decades or even centuries. However, developing such a cap may require experimenting with different combinations and arrangements of natural soils and synthetic membranes. The results of generic research could be applied nationwide. However, subjecting prospective cap designs to several years of testing under actual conditions would have to be conducted at or near actual disposal sites. In fact, it may require a decade or so to find the most appropriate cap designs for a particular humid region of the country.

Development of waste disposal facilities in humid regions need not be delayed while the performance of caps is tested in site-specific, long-term demonstration projects. Waste disposal units can be covered with a cap that could be replaced or covered over later if an alternative cap design proves more durable. If vaults are used, it may be possible to leave them uncovered until a cap that has performed well in a demonstration project is constructed. When effective caps are constructed and their performance verified *over a few decades*, it may be possible to eliminate some engineered features from later disposal units, thereby reducing future disposal costs.

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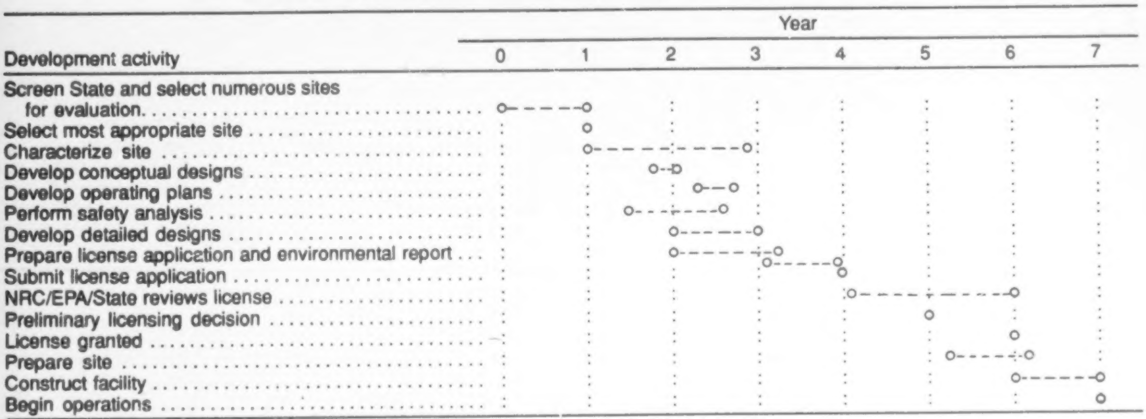
[27] EPA believes that double liners and leachate collection systems are necessary in arid regions because of few, but intense periods of rainfall (written comments from Glen Galen, U.S. Environmental Protection Agency, Sept. 13, 1989). In contrast, arid site developers believe that these features will unnaturally trap water and increase contaminant migration (comments from Tom Baer, US Ecology, Inc., OTA Review Panel, Washington, D.C., Aug. 18, 1989).

[28] It should be noted that lawsuits will likely impede this schedule significantly.

[29] Riprap may have to be used instead of vegetation on steeper, highly erosive slopes or in places where precipitation is insufficient to support vegetation.

Table 6-3—Optimistic Schedule for Developing a Disposal Facility[a]



[a] It is likely that lawsuits will be filed and that this optimistic schedule will be significantly delayed.

SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal," prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987.

REMEDIATING LEAKING DISPOSAL FACILITIES

Preventive Measures

Waste constituents that leak from disposal sites into the environment are often very difficult and expensive to cleanup. Under certain contamination scenarios, the waste may have to be removed from the facility, treated, and "redisposed" in a new facility. To prevent waste migration and costly redisposal operations, it will likely prove cost effective to invest in any one of the following, sequential activities:

1. **Careful facility development**: Waste disposal facilities will perform best if they are properly sited, designed, and/or constructed in accordance with widely accepted engineering practices. Whenever possible, "passive" features (e.g., downslope drainage) should be used instead of "active" features (e.g., pumping). If a disposal facility has not been properly developed, correcting some problems with available engineering techniques may be possible (18); otherwise, a facility may never function as intended.
2. **Monitoring and improving the cap**: Monitoring operations that quickly detect any leaks in a cap can avoid costly redisposal operations. Since a cap is only a small percentage of the cost of an entire disposal facility, a cap can be improved or replaced at a fraction of the cost of removing the waste from an inadequate facility and redisposing the waste elsewhere. **Repairing, replacing, or recapping leaking caps (or sections of caps) is probably the best route to long-term remediation.**
3. **Water removal and treatment**: If the bathtub effect saturates below-grade trenches, it may be necessary to periodically pump the water out and treat any contaminated water with available water treatment techniques prior to offsite discharge.

The likelihood that a facility will need remediation increases where the annual precipitation is higher and when waste remains harmful longer. Although longer-lived radioactive wastes and mixed LLWs with environmentally persistent hazardous constituents account for only a small percent of all LLW, **it may be prudent to build into the disposal fees the costs of potential remediation.**

Removing Waste From Disposal Units

The public's acceptance of a waste disposal operation will generally increase if the waste can be removed from a disposal facility at a later date if necessary. Waste packed in high-integrity containers or concrete overpacks would make removal easier. However, the more isolated the waste is after disposal, the more difficult and expensive removal becomes. Overall, the ease and cost of waste removal depends largely on the design and size of the disposal units and the timing of the removal.[30] In general, **the removal of waste from a capped disposal facility should be considered only as a last resort**.

Disposal Units Without Concrete Vaults

Waste containers are easily removed from a trench or tumulus prior to the emplacement of a permanent soil cap. After this time, the ease with which the waste can be removed depends largely on the integrity of the containers holding the waste. High-integrity containers and/or concrete overpacks will generally make waste removal easier for the first few decades after disposal; much later, however, waste removal will be increasingly difficult as the waste containers or overpacks gradually degrade.

Cement grout can be poured or injected into and around all the waste packages or overpacks emplaced in a trench or tumulus. Although grouting will increase the stability of the waste packages and help prevent any infiltrating water from percolating around or through the waste, grouting makes it very difficult to remove waste from a disposal unit.

Disposal Units With Concrete Vaults

It is usually quite easy to remove ungrouted waste from a concrete vault **before vault closure**. If the vault is designed to be loaded through an open side, the waste can be removed in the same manner in which it was emplaced. However, removing a specific container of waste from inside the vault may require first removing many containers around it. For top-loaded vaults, a stack of waste containers can usually be easily removed before the roof is emplaced.[31]

Removing ungrouted waste from a vault **after closure** may be relatively easy or very difficult. For top-loaded vaults with roof segments that can be lifted off the vault with a crane, waste removal may be quite easy. For most other vault designs without removable roofs, waste removal would involve breaking through a 2 to 3 foot thick concrete roof or vault wall. Waste removal would also involve stripping away all or part of the permanent cap.

For vaults where the space between waste packages or overpacks is grouted, waste removal would be extremely difficult. Grouting, however, probably would not be necessary because of the high level of stability provided by the vault itself.

Long-Term Monitoring

NRC regulations require up to 100 years of institutional control of disposal sites after closure to ensure that the disposal facilities are performing as designed and to provide some protection against inadvertent intrusion (10 CFR Part 61.59). At the end of this post-closure period, the license will be terminated and the site released for restricted or unrestricted use, depending on the nature of the disposed LLW and past performance of the site. According to EPA regulations, land disposal facilities for hazardous wastes must be monitored and maintained for 30 years after facility closure. Depending on the performance of the site, this period can be shortened or extended by EPA.

The level of public confidence in the long-term performance of waste disposal facilities can be increased by long-term monitoring. **Since Class B, C, and some mixed LLW will remain harmful well beyond 100 years, some States plan to monitor the disposal facilities containing these wastes for as long as the waste remains harmful.**

Disposal facilities, especially those in humid regions, may perform well over the short-term but may deteriorate after a few decades. The frequency of monitoring disposal facilities may have to be increased with time as the concrete and other structural components used in the overpacks and vaults degrade with age. It may be prudent to incorporate any assumptions about the necessity for long-term monitoring into the disposal costs for these long-lived wastes.

POTENTIAL AREAS FOR TECHNOLOGY IMPROVEMENT

Due to the low cost of caps and their accessibility (compared to other components of a waste disposal facility), it is relatively inexpensive to repair, recap, or replace a leaking cap. However, to begin with, cap designs should be tailored to regional climate conditions. **Developing better combinations of soil layers and synthetic membranes, particularly for humid regions, probably holds the greatest potential for improving the performance of past and future near-surface disposal facilities.** These development efforts as well as long-term, onsite demonstrations may also benefit from advances in containment systems for hazardous waste landfills.

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[30] The term **retrieval** commonly refers to the removal of waste from a disposal unit **prior** to the installation of a permanent, multilayered cap. During this time, waste containers or overpacks would probably remain intact. Easy retrievability provides the option of removing the waste from a disposal unit if the waste needs to be moved for some reason. **Recovery** commonly refers to the removal of waste from a disposal unit at some time **after** a permanent, multilayered cap has been emplaced and usually well after closure of the disposal facility. Depending on the timing of recovery, waste containers or overpacks may or may not be totally intact.

[31] Since vaults will probably provide all the stability necessary for a disposal facility, the use of high-integrity containers for waste packages may be unnecessary. However, high-integrity containers may make it somewhat easier to load or unload the waste.

Additional studies could also focus on improved monitoring systems that can be located inside the lower portion of a multilayered cap so that leaks in the cap can be identified and repaired as quickly as possible. In addition, if settling of a facility was significant, the integrity of any drainage pipes that run under disposal units to monitoring ports could be damaged or completely crimped so that they are rendered useless. If this problem occurred, any water migrating from a disposal facility without an in-cap monitoring system would not be discovered until it reached the monitoring stations surrounding the facility.

Small-scale or prototype disposal units at each disposal site offer an opportunity for long-term, onsite demonstrations. In addition, closely monitored test facilities may be useful to better evaluate the overall and long-term performance of all disposal units within a site.

DISPOSAL COSTS[32]

The average cost per cubic foot of waste, or **unit disposal cost**, has increased significantly for all LLW over the last two decades. For example, unit disposal costs for most Class A LLW steadily increased from about $1 per cubic foot in 1975 to about $15 per cubic foot in 1980; disposal costs tripled between 1980 and 1986 (11). These cost increases stem primarily from two causes. First, compliance with NRC and State regulatory requirements developed in the early 1980s added to disposal costs. Second, the LLRWPAA created an optional schedule of increasingly higher surcharges for waste originating outside a disposal site's compact. As shown in table 6-4, there are additional penalties for generators if their respective compacts do not meet the milestones established in the LLRWPAA.

At the beginning of 1988, the minimum fees (including surcharges) charged by the three different LLW sites ranged from about $38 to $46 per cubic foot for dry Class A LLW (see table 6-5).[33] **Disposal costs will likely increase substantially in 1990 when the surcharge increases from $20 to $40 per cubic foot.**

Unit disposal costs are especially sensitive to the facility design, the annual waste capacity of the disposal facility, and the mode of financing used for facility development. As shown in table 6-6, **more elaborate facility designs can cost almost twice as much as shallow-land burial** now used at all three commercial sites. Table 6-6 also indicates that **unit disposal costs increase significantly as the capacity of the facility decreases**. For example, unit disposal costs increase by a factor of two as facility capacities decrease from 350,000 to 150,000 cubic feet per year. Moreover, as shown in figure 6-11, unit disposal costs increase by a factor of four as facility capacities decrease from 60,000 to 10,000 cubic feet per year. Finally, **private financing will increase disposal costs about 10 to 31 percent over public financing**, depending on the design and capacity of the facility (see table 6-7).

Unit disposal costs for LLW will undoubtedly increase over the next few years for four reasons. First, as shown in table 6-4, the surcharges on waste disposal will increase before States and compacts develop new disposal facilities. Second, as LLW volumes decrease, unit disposal costs at disposal sites will increase to cover fixed operating costs. Third, unit disposal costs at new disposal facilities may be higher, especially if: 1) more expensive disposal technologies are used, 2) new disposal facilities are smaller, and/or 3) waste packaging requirements are more stringent. Fourth, disposal costs for Class B, C, and mixed LLW may increase due to a recognized need for long-term monitoring and potential remediation.

Unit disposal costs will probably vary significantly from one State or compact to another for three reasons. First, the volumes of LLW generated

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[32] Overall disposal costs cover the following items: disposal facility construction and operation; any surcharges (table 6-4); and extended custodial care, monitoring, possible remedial action, and administrative costs. The LLRWPA and its 1985 amendments do not set legal limits on fees that a disposal site may charge.

[33] These fees rise dramatically with increased radioactivity in the waste.

Table 6-4—Surcharges for LLW Disposal (dollars per cubic foot)

Milestone	States achieving milestones: Year	States achieving milestones: Normal surcharge	States failing milestones: Year	States failing milestones: Revised surcharge
7/86	1986-1987	$10/ft³	1/86 to 7/86	$10/ft³
			7/86 to 1/87	$20/ft³
			1/[illegible]—site access may be denied	
1/88	1988-1989	$20/ft³	1/88 to 7/88	$40/ft³
			7/88 to 1/89	$80/ft³
			1/89—site access may be denied	
1/90	1990-1992	$40/ft³		
1/92		$80/ft³		$120/ft³
1/93		Site access denied	States take title to LLW or refund to generators 25% of surcharges paid during previous 3 years.	
1/96			States take title to LLW.	

NOTE: See also table 2-1.

SOURCE: Office of Technology Assessment, 1989.

Table 6-5—Approximate 1988 Disposal Costs for Class A LLW (dollars per cubic foot)

Site location	Volume disposed (ft³ for 1988)	Disposal charge	Surcharge	Total cost
Richland, WA	403,303	$18	$20	$38.00
Barnwell, SC	931,602	26	20	46.00
Beatty, NV	100,852	24	20	44.00
Total	1,435,757		Average	$42.67

SOURCE: Lawrence P. Matheis, Nevada State Health Division, letter to Leonard Slosky, Rocky Mountain Low-Level Radioactive Waste Board, Feb. 29, 1988. U.S. Department of Energy, Draft, "Integrated Data Base for 1988: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 5, August 1989 p. 157.

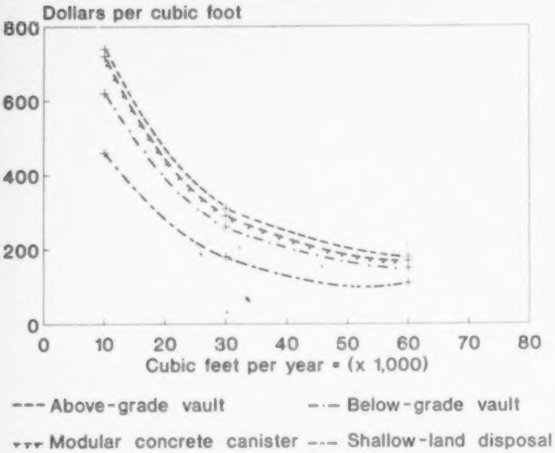
Table 6-6—Approximate Unit Disposal Costs Without Surcharges (dollars per cubic foot)[a]

Disposal facility	Facility capacity in thousands of cubic feet/year: 10	60	50	230	350
Below-grade facilities					
Shallow-land burial	$460	$110	$ 55	$40	$30
Concrete containers	$590	$140	$ 80	$55	$40
Concrete vaults					
Above-grade, earth-covered facilities					
Concrete containers	$670	$160	$ 90	$65	$50
Concrete vaults					
Above-ground vaults (no earthen cover)					
Earth-mounded concrete bunkers	$780	$180	$105	$75	$55

[a] Costs assume public financing of the disposal facility.

SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal," prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987, pp. 12-24, p. 25; U.S. Department of Energy, "1987 Annual Report on Low-Level Radioactive Waste Management Program," August 1988, pp. 17-19; EG&G Idaho, "Facility Life Cycle Cost and Average User Fee Projections for Small-Volume Low-Level Radioactive Waste Disposal Facilities," DOE Contract No. DE-AC07-76IDO1570, February 1989; Rogers & Associates Engineering Corp., "Conceptual Designs and Preliminary Economic Analyses of Four Low-Level Radioactive Waste Disposal Facilities," October 1987; US Ecology, Inc., "Proposal for Development and Operation of the Appalachian States Low-Level Radioactive Waste Compact Regional Disposal Facility," prepared for the Commonwealth of Pennsylvania, Vol. II: Executive Summary, p. 18, and Vol. III: Technical Presentation, October 1988; Julie Conner, EG&G Idaho, personal communication, May 1989.

Figure 6-11—Effects of Waste Volume on Unit Disposal Costs



SOURCE: EG&G Idaho, Inc., "Facility Life Cycle Cost and Average User Fee Projections for Small-Volume Low-Level Radioactive Waste Disposal Facilities," prepared under DOE Contract No. DE-AC07-76ID01570, February 1989.

Table 6-7—Effect of Financing on Unit Disposal Costs for Shallow-Land Burial and Below-Grade Vaults (dollars per cubic foot)

	Facility capacity in thousands of cubic feet/year		
Financing	10	60	230
Shallow-land burial:			
Public	$360	$ 90	$33
Private	$460	$110	$40
Incremental cost of private financing	28%	22%	18%
Below-grade vaults:			
Public	$450	$110	$50
Private	$590	$140	$55
Incremental cost of private financing	31%	27%	10%

SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal," prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987, pp. 12-24, p. 25; EG&G Idaho, "Facility Life Cycle Cost and Average User Fee Projections for Small-Volume Low-Level Radioactive Waste Disposal Facilities," DOE Contract No. DE-ACO7-76IDO157, February 1989.

by different States and compacts vary considerably. As shown in appendix A, the Southeast Compact generates about 500,000 cubic feet per year, whereas the Rocky Mountain Compact generates about 4,000 cubic feet per year. Second, disposal facilities located in humid regions will probably be more expensive than facilities in arid regions of the country due to the added design features required to minimize the infiltration of precipitation. Third, disposal facility costs vary according to local economic conditions, such as land values and labor and material costs, and according to State and local regulations.[34]

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[34] It is important to recognize that unit disposal costs are influenced by assumptions about specific characteristics of sites and facility designs, cost of capital, inflation, liability insurance, tax rates, operating lifetime of the facility, and many other factors incorporated into various cost models. Due to the variation among disposal facility development costs, **each State or compact will need to obtain site-specific cost estimates for its respective site using updated and realistic financial assumptions.**

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Appendixes

Appendix A

Volumes of Commercial LLW Shipped for Disposal by State (as reported by disposal site operators)[a]

State	Annual volume in thousands of cubic feet					
	1983	1984	1985	1986	1987	1988
Northeast Compact						
New Jersey (H)	128	116	66	56	50	38
Connecticut (H)	67	58	63	56	40	40
Subtotal	195	174	129	112	90	78
Appalacian Compact						
Pennsylvania (H)	270	219	262	188	145	145
Maryland[b]	47	42	38	19	20	26
Delaware	1	1	1	1	1	1
West Virginia	<1	<1	<1	<1	<1	<1
Subtotal	319	263	302	209	166	172
Southeast Compact						
Tennessee[b]	159	240	237	81	239	161
South Carolina[b]	198	255	136	121	118	96
Virginia	167	98	147	71	68	64
North Carolina[b](H)	166	100	102	82	79	62
Alabama[b]	154	151	102	58	70	51
Georgia[b]	69	87	78	48	30	39
Florida[b]	85	89	59	60	46	31
Mississippi[b]	15	15	22	19	14	18
Subtotal	1,013	1,035	883	540	664	522
Midwest Compact						
Michigan (H)	54	38	55	36	35	25
Ohio	28	19	34	16	19	20
Minnesota	44	70	47	28	20	14
Missouri	8	7	11	24	23	10
Wisconsin	28	29	16	6	9	18
Iowa[b]	26	12	30	10	19	7
Indiana	<1	3	1	0	2	2
Subtotal	189	178	194	120	127	96
Central Midwest Compact						
Illinois[b] (H)	219	227	360	227	190	126
Kentucky[b]	3	2	4	4	<1	2
Subtotal	222	229	364	231	191	128
Central States Compact						
Oklahoma	2	5	11	50	83	28
Louisiana[b]	<1	<1	11	23	28	18
Nebraska[b] (H)	35	31	37	20	17	13
Arkansas[b]	28	33	25	4	20	7
Kansas[b]	0	1	2	7	5	5
Subtotal	66	71	86	104	153	71
Rocky Mountain Compact						
Colorado[b] (H)	3	9	10	1	4	3
New Mexico[b]	1	1	3	0	1	<1
Nevada[b]	0	0	<1	0	<1	<1
Wyoming	0	0	0	0	0	0
Subtotal	4	10	14	1	6	4

(H) = States planning to host a disposal facility.

[a] Pre-1980 volumes are inaccurate in that waste brokers did not attribute the waste they shipped for disposal back to the original waste generator.

State	Annual volume in thousands of cubic feet 1983	1984	1985	1986	1987	1988
Northwest Compact						
Oregon[b]	49	60	58	109	82	84
Washington[b] (H)	45	45	63	53	38	36
Utah[b]	3	5	5	3	3	5
Hawaii	5	3	11	2	3	4
Idaho[b]	0	6	1	0	<1	<1
Montana	<1	1	<1	1	<1	0
Alaska	0	0	0	0	<1	0
Subtotal	103	120	139	168	129	129
Southwestern Compact						
California[b] (H)	133	159	251	114	99	74
Arizona[b]	0	1	4	5	17	28
North Dakota[b]	0	0	0	0	<1	0
South Dakota	<1	0	<1	<1	0	0
Subtotal	133	160	255	119	116	102
Unaffiliated States						
New York[b] (H)	199	147	161	107	70	65
Massachusetts (H)	167	193	106	67	55	47
Texas[b] (H)	57	13	11	4	69	9
Vermont	22	13	20	12	8	7
Maine (H)	12	12	13	8	5	6
Rhode Island[b]	2	1	1	1	1	1
New Hampshire[b]	2	2	2	2	<1	<1
District of Columbia	3	2	1	<1	<1	<1
Subtotal	464	383	315	201	208	135
Total	2,709	2,619	2,681	1,805	1,845	1,436

(H) = States planning to host a disposal facility.

[b] Agreement States.

SOURCE: Data for 1983 through 1987 taken from *The 1987 State-by-State Assessment of Low-level Radioactive Wastes Received at Commercial Disposal Sites*, National Low-level Radioactive Waste Management Program, December 1988, DOE/LLW-69T, pp. 141. Data for 1988 taken from tables prepared by EG&G Idaho in May 1989 for the U.S. Department of Energy, *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, 1989.

Appendix B
Decommissioning of Nuclear Power Plants

Although most nuclear power plants are licensed by the Nuclear Regulatory Commission to operate for 40 years, there is no absolute age at which they become unsafe or uneconomical to operate. In fact, it may be possible to economically extend the operating lifetime of many reactors simply by replacing aging internal components. Once a plant has been shut down, it can be decommissioned (e.g., dismantled) within a few years, placed in safe storage for 30 to 50 years prior to decommissioning, or permanently entombed.

There are two reasons for delaying decommissioning once a reactor has been shut down. First, as shown in the table below, the overall radioactivity of the LLW from decommissioning will decrease by 30 to 45 times, if decommissioning is deferred five decades. Deferral could therefore reduce worker risks and decrease dismantling costs. Second, the volumes of Class A, B, and C LLW generated from immediate decommissioning can be reduced by about 10 times if decommissioning is deferred five decades.

Effects of Delayed Decommissioning on the LLW Generated by Commercial Nuclear Power Plants

Plant type [1.175 GW(e)]	No delay	30-year delay	50-year delay
Radioactivity of all LLW in thousands of curies:			
Boiling-water	6,600	180	140
Pressurized-water	4,900	210	160
Volume of all LLW in thousands of cubic feet:			
Boiling-water	670	670*	60*
Pressurized-water	630	630*	65*

*Includes wastes from both preparation for storage *and* decommissioning.

SOURCE: U.S. Department of Energy, *Integrated Data Base for 1988: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 4, September 1988, p. 185.

For these reasons, many of the 113 operating nuclear plants, especially the approximately 70 plants that are colocated with other units, may be placed in "SAFESTOR" for five decades prior to decommissioning. It is not clear, however, that decommissioning of all nuclear plants will be deferred. If costs for LLW disposal continue to rise as they have over the last 15 years, it may be more economical to immediately decommission some plants. For example, older plants (i.e., constructed prior to 1970) that do not have well-documented designs and are not colocated with multiple units may be more economically decommissioned shortly after permanent shutdown before plant engineers are reassigned or retired.

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